Non-protein Nitrogen, Phosphorus and Magnesium in Ruminant Nutrition

by

WILLIAM GORDON HILLIS

A DISSERTATION PRESENTED TO THE GRADUATE COUNCIL OF
THE UNIVERSITY OF FLORIDA IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA
1971

ACKNOWLEDGMENTS

Sincere appreciation is extended to Dr. C. B. Ammerman, Chairman of the Supervisory Committee, for his support and guidance throughout the academic program and experimental investigations; and also to Drs. J. E. Moore, J. A. Himes, R. H. Harms and C. M. Allen, Jr. for serving as members of the supervisory committee and for giving freely of their time and knowledge toward the completion of this work.

The author is grateful for the assistance given him by many of the graduate students, particularly Larry T. Watson and Karl R. Fick. Sincere appreciation is also expressed for the technical assistance of Mrs. Sarah Miller, Mr. John F. Easley and other members of the staff of the Nutrition Laboratory. The assistance provided by Mr. Phil Hicks in caring for experimental animals is acknowledged.

Special appreciation is expressed to International Minerals and Chemical Corporation, Skokie, Illinois, and the National Feed Ingredients Association, Des Moines, Iowa, for providing financial assistance for this work. The provision of experimental supplies by Charles Pfizer and Co., Inc., Terre Haute, Indiana, American Cyanamid Company, Princeton, New Jersey and Monsanto Chemical Co., St. Louis, Missouri is acknowledged.

Sincere appreciation is extended to Mrs. Ella Mae Huber for typing this manuscript.

The author is especially grateful to his wife, Wilma, for her help and inspiration during this period of academic endeavor. To her this work is dedicated.

TABLE OF CONTENTS

Page

ACKNOWLEDGMENTS. ii

LIST OF TABLES vi

LIST OF FIGURES. xii

ABSTRACT xiv

CHAPTER

I INTRODUCTION. 1

II LITERATURE REVIEW 3

Non-protein Nitrogen Utilization by Ruminants 3
Inorganic Phosphate Supplements for Ruminants 9
Effect of Age on Magnesium Utilization. . . 14
Magnesium Requirement and Availability. . . 17

III EFFECT OF LEVELS AND SOURCES OF SUPPLEMENTAL NITROGEN ON VOLUNTARY FEED INTAKE, AVERAGE DAILY GAIN AND BLOOD UREA-N IN STEERS . . . 28

Procedure and Results 29

Experiment 1--Effect of Supplemental Nitrogen as Soybean Meal, DAP, Urea and DAP Plus Urea on Voluntary Feed Intake and Average Daily Gain in Steers. . . . 29
Experiment 2--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers. 31
Experiment 3--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers. 37

CHAPTER Page

Experiment 4--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers. 40

Discussion. 44

IV NITROGEN SOURCE AND RUMEN AMMONIA, pH AND BLOOD UREA-N. 46

Procedure and Results 46

Experiment 1--Effect of Nitrogen Source on Rumen Ammonia, pH and Blood Urea-N . 46

Experiment 2--Effect of Nitrogen Source and Supplemental Acid or Base on Rumen Ammonia, pH and Blood Urea-N. 57

Discussion. 64

V THE PHOSPHORUS AVAILABILITY IN MONOAMMONIUM AND MONOSODIUM PHOSPHATES FOR GROWING LAMBS 70

Procedure and Results 70

Discussion. 78

VI EFFECT OF AGE AND DIETARY LEVEL OF MAGNESIUM ON MAGNESIUM UTILIZATION BY SHEEP 80

Procedure and Results 80

Discussion. 108

VII GENERAL SUMMARY 115

Influence of Non-protein Nitrogen Source on Feed Intake, Animal Performance and Blood Urea-N. 115

Effect of Nitrogen Source on Certain Blood and Ruminal Fluid Constituents. . 116

Relative Availability of Phosphorus in Two Inorganic Phosphorus Sources. . . . 117

Influence of Age and Dietary Magnesium Level on Magnesium Utilization. 117

APPENDIX 120

BIBLIOGRAPHY 159

BIOGRAPHICAL SKETCH. 168

LIST OF TABLES

TABLE Page

1 COMPOSITION OF DIETS 30

2 EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION AND AVERAGE WEIGHT GAIN. 32

3 COMPOSITION OF DIETS 34

4 EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN) 35

5 COMPOSITION OF DIETS 38

6 EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN) 39

7 COMPOSITION OF DIETS 41

8 EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN) 43

9 COMPOSITION OF DIET. 48

10 EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON RUMEN pH. 49

11 EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON RUMEN AMMONIA-N 52

12 EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON BLOOD UREA-N. 55

13 EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON RUMEN pH. 59

TABLE Page

14 EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON RUMEN AMMONIA-N. 62

15 EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON BLOOD UREA-N 65

16 COMPOSITION OF DIETS. 71

17 AVERAGE INITIAL AND FINAL WEIGHT, DAILY GAIN, FEED INTAKE AND FEED EFFICIENCY OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL . . 74

18 AVERAGE PHOSPHORUS, CALCIUM AND MAGNESIUM LEVELS IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL 76

19 AVERAGE MEASUREMENTS AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL. 77

20 COMPOSITION OF EXPERIMENTAL DIET. 82

21 AGE SPECIFICATIONS, BODY WEIGHTS AND FEED OFFERED 83

22 EFFECT OF AGE AND DIETARY MAGNESIUM ON APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP 86

23 EFFECT OF AGE AND DIETARY MAGNESIUM ON NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP 88

24 EFFECT OF AGE AND DIETARY MAGNESIUM ON URINARY EXCRETION AS PERCENT OF INTAKE OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP. 90

25 EFFECT OF AGE AND DIETARY MAGNESIUM ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP 91

TABLE Page

26 INDIVIDUAL DATA ON EFFECT OF NITROGEN ON FEED CONSUMPTION AND AVERAGE WEIGHT GAIN. . 121

27 INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN). 122

28 INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN). 123

29 INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN). 124

30 INDIVIDUAL DATA ON RUMEN pH OF SHEEP DOSED WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE 125

31 INDIVIDUAL DATA ON RUMEN AMMONIA-N OF SHEEP WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE 126

32 INDIVIDUAL DATA ON BLOOD UREA-N OF SHEEP DOSED WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE 127

33 INDIVIDUAL DATA ON RUMEN pH OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE 128

34 INDIVIDUAL DATA ON RUMEN AMMONIA-N OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE AND MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE 129

35 INDIVIDUAL DATA ON BLOOD UREA-N OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE 130

36 INDIVIDUAL DATA ON DAILY GAIN, FEED INTAKE AND FEED EFFICIENCY OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL 131

TABLE Page

37 INDIVIDUAL DATA ON PHOSPHORUS LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL 132

38 INDIVIDUAL DATA ON CALCIUM LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL. 133

39 INDIVIDUAL DATA ON MAGNESIUM LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL 134

40 INDIVIDUAL DATA ON MEASUREMENTS AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL . . 135

41 INDIVIDUAL DATA ON MEASUREMENT AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL . . 136

42 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. 137

43 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. 138

44 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. 139

45 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. . . . 140

46 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. 141

TABLE Page

47 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS. 142

48 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE. 143

49 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE 144

50 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE. 145

51 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML) 146

52 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML) 147

53 INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML) 148

54 INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY. 149

55 INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY. 150

56 INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY. 151

TABLE Page

57 INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY 152

58 INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY. 153

59 INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY. 154

60 INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY 155

61 INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY 156

62 INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY . . 157

63 INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO PLASMA MAGNESIUM 158

LIST OF FIGURES

FIGURE Page

1 EFFECT OF TREATMENTS ON RUMEN pH. 50

2 EFFECT OF TREATMENTS ON RUMEN AMMONIA-N . . . 53

3 EFFECT OF TREATMENTS ON BLOOD UREA-N. 56

4 EFFECT OF TREATMENTS ON RUMEN pH. 60

5 EFFECT OF TREATMENTS ON RUMEN AMMONIA-N . . . 63

6 EFFECT OF TREATMENTS ON BLOOD UREA-N. 66

7 RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY 93

8 RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY 95

9 RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY . . 96

10 RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY 97

11 RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY 99

12 RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY . . 100

13 RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY. 102

14 RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY. 104

FIGURE Page

15 RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY. 106

16 RELATION OF URINARY MAGNESIUM TO PLASMA MAGNESIUM 107

Abstract of Dissertation Presented to the Graduate Council
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

NON-PROTEIN NITROGEN, PHOSPHORUS AND MAGNESIUM IN RUMINANT NUTRITION

By

William Gordon Hillis

August, 1971

Chairman: Dr. C. B. Ammerman
Major Department: Animal Science

Studies were conducted to obtain information on certain nutritional aspects of non-protein nitrogen, phosphorus and magnesium in steers and sheep.

Four Latin square designed experiments were conducted with steers to examine the effects of urea, diammonium phosphate (DAP) and monoammonium phosphate (MAP) on feed consumption, average daily gain and blood urea-N. In Experiments 1 and 3 voluntary feed intakes were significantly ($P< .05$) reduced with diets containing 1.5% DAP and in Experiment 2 with a diet containing 2.3% MAP. Treatment diets containing MAP consistently resulted in the lowest average daily gains. At the end of each experimental period steers were fasted 12 hours followed by 2 hours *ad libitum* consumption of their respective treatment diets. The increase in blood urea-N following the 2-hour feeding period was greater for treatments containing isonitrogenous levels of non-protein nitrogen (1.5% DAP and 2.3% MAP) except in Experiment 2 where 0.75% MAP resulted in the greatest blood urea-N increase.

Two Latin square designed experiments were conducted with fistulated sheep to study the effects of non-protein nitrogen sources upon rumen ammonia-N, pH and blood urea-N. All nitrogen sources were administered intraruminally as 10 gm of nitrogen per 45.4 kg body weight and rumen fluid and jugular blood samples were taken at periodic intervals thereafter. In the first experiment urea resulted in the greatest ($P < .05$) increase in rumen pH, the least ($P < .05$) increase in rumen ammonia-N concentration and the greatest ($P < .05$) increase in blood urea-N. Converse responses resulted with MAP and DAP was intermediate in effect. Treatments in the second experiment consisted of urea, urea plus H_3PO_4, MAP and MAP plus Na_2CO_3. Effects of alkali and acid additions on rumen pH were of short duration. Blood urea-N values for the urea and urea plus H_3PO_4 treatments were similar throughout the sampling period and values for the treatments MAP and MAP plus Na_2CO_3 were similar.

A balance trial was conducted with sheep of three ages (lambs, yearlings and adults) receiving three dietary levels of magnesium and a computed maintenance level of energy intake. With increasing age, the retention of calcium and phosphorus decreased, apparent absorption of calcium decreased, plasma inorganic phosphorus decreased and excretion of phosphorus in urine increased. With increasing intakes of dietary magnesium, there was a decreased retention of phosphorus and calcium, increased excretion of calcium in urine and increased apparent absorption, retention, urinary excretion and plasma levels of magnesium. By use of regression analysis (fecal magnesium on magnesium intake) the theoretical values for metabolic fecal magnesium were calculated for lambs, yearlings and adults to be: 170.91, 122.25 and 118.44 mg per 1,000 kilocalories of metabolizable energy (ME) intake per day, respectively; 16.87, 13.95 and 12.30 mg per $kg^{0.75}$ body weight per day, respectively; 7.26, 5.48 and 4.25 mg per kg body weight per day, respectively. From the regression equations of fecal plus urinary magnesium on magnesium intake for each age group the calculated minimum dietary requirements to replace endogenous losses for lambs, yearlings and adults were: 261.07, 235.20 and 176.46 mg per 1,000 kilocalories of ME intake per day, respectively; 28.84, 26.40 and 20.46 mg per $kg^{0.75}$ body weight per day, respectively; 12.56, 10.50 and 6.75 mg per kg body weight per day. respectively. These values would be specific for the semi-purified diet fed with supplemental magnesium provided as the carbonate. The regressions of urinary magnesium on plasma magnesium gave renal threshold values for lambs, yearlings and adults of: 1.38, 1.42 and 1.21 mg per 100 ml of plasma, respectively.

CHAPTER I

INTRODUCTION

Maximum efficiency in animal production is dependent upon providing optimum quantities of all essential nutrients. To obtain such efficiency, knowledge must be present of the relative availabilities of nutrients in the various feed ingredients and as well the acceptability to the animal of the nutrient sources.

Although it has been adequately demonstrated that the protein needs of ruminants can be met by supplementing their diets with non-protein nitrogen, a problem still remains as to the source of this form of nitrogen most desirable to use. Certain forms of non-protein nitrogen have been found less toxic than the commonly used compound,urea. However, some of these less toxic forms, such as diammonium phosphate, have been reported less acceptable to animals than urea. An advantage of using such compounds as diammonium phosphate or monoammonium phosphate is their property of being a source of both non-protein nitrogen and supplementary phosphorus.

A problem common to all sources of non-protein nitrogen is their rapid release of ammonia in the rumen. A reduction in the rate of absorption of such ammonia would contribute to the efficiency of its utilization in the rumen by prolonging its availability to the rumen microbes for protein synthesis. Supplying phosphate with the sources of non-protein nitrogen is thought to buffer rumen pH and reduce ammonia absorption and nitrogen wastage.

Magnesium, which is only one of many minerals known to be essential for maximum production efficiency, has been the subject of considerable research in recent years. The objective of many of the studies was to elucidate the role of magnesium in hypomagnesaemic tetany. It has been suggested that the older animal is more susceptible to this disease due to a decreased ability to mobilize skeletal magnesium with age. Thus the older animal may be almost entirely dependent on daily supplies of magnesium to maintain normal metabolism.

This research was conducted to evaluate several non-protein nitrogen sources and, as well, to investigate the effect of age on magnesium utilization in ruminants. Urea, diammonium phosphate and monoammonium phosphate were evaluated with respect to their relative acceptabilities by steers and their utilizations by steers and sheep. A lamb growth and slaughter study was also conducted to determine the availability of phosphorus from monoammonium phosphate. The effect of age on dietary magnesium utilization was examined in a balance study involving three age levels of sheep.

CHAPTER II

LITERATURE REVIEW

The literature dealing with non-protein nitrogen, phosphorus and magnesium as they relate to animal nutrition is extensive. Only those articles having a direct relationship to the work conducted by the author and giving a basic knowledge of the related areas will be reviewed.

Non-protein Nitrogen Utilization by Ruminants

The protein needs of the world's expanding population continue to receive the attention of nutritionists. Protein supplements, which in the past have been used routinely for supplementing ruminant rations, are now finding new roles as protein sources for human nutrition. Such uses may result in prices that will prohibit their use in ruminant diets in the future. For this and other reasons considerable research has been conducted on the use of non-protein nitrogen sources as substitutes for natural protein supplements.

Early work conducted by Hart et al. (1939) demonstrated that dairy heifers could utilize the nitrogen of urea for growth and that adding soluble sugars to the diet improved this utilization. Since that time much research has been directed toward finding optimal conditions for efficient utilization of non-protein nitrogen.

A major problem resulting in inefficient utilization of urea is the rapid release of ammonia. Bloomfield, Garner and Muhrer (1960) indicated that urea hydrolysis occurred four times faster in the rumen than uptake of the liberated ammonia by the microorganisms. The need for adequate levels of readily-available carbohydrate for better utilization of urea and other non-protein nitrogen compounds has been well demonstrated (Arias et al., 1951; Belasco, 1956; Bloomfield, Muhrer and Pfander, 1958; Bloomfield, Wilson and Thompson, 1964; McLaren et al., 1965).

Rumen ammonia concentration, either singly or together with other parameters, has often been used as a measure of the hydrolyzability of nitrogen supplements or of the relative microbial protein synthesis from such supplements. It should be pointed out, however, that ammonia concentration in the rumen, just like that of any other rumen metabolite, is dependent upon the following forces as enumerated by Annison and Lewis (1959): rate of production, rate of utilization by microbes, rate of absorption through the rumen wall, dilution by saliva and water, and passage to the omasum.

McDonald (1948), working with sheep, found much of the excess ammonia which the microbes are not able to utilize is absorbed from the rumen with some ammonia absorption occurring in the omasum, lower part of the small intestine and cecum. Ammonia absorption is governed by both concentration gradient and pH. Lewis (1957) demonstrated that the portal blood ammonia concentration increased as a curvilinear function of rumen ammonia content. Hogan (1961), working with anesthetized sheep, also demonstrated ammonia absorption to be dependent on the concentration gradient when the rumen contents were maintained at a pH of 6.5, but ammonia loss was nil at pH 4.5. Bloomfield _et al._ (1963), working with fistulated sheep, reported a reduction in absorption of ammonia from 26 to 0 mM/L/hour when the rumen pH was reduced from 7.55 to 6.21. Since ammonia is a weak base with a pKa of 8.8 at 40°C, the increased absorption of ammonia at a higher pH is probably the result of an increase in the amount of the neutral and smaller ammonia molecule, in relation to ammonium ion, which may more readily penetrate the lipid layers of the rumen mucosa (Coombe, Tribe and Morrison, 1960; Hogan, 1961; Bloomfield _et al._, 1963; Visek, 1968). Unfortunately, the alkaline buffering capacity of rumen fluid is not as great as its acid buffering capacity (Clark and Lombard, 1951; Ammerman and Thomas, 1955; Bloomfield _et al._, 1966). Thus, conditions in the rumen from urea feeding are conducive not only to rapid production but also to increased absorption of ammonia.

The use of non-protein nitrogen sources as partial substitutes for natural protein has been limited by their toxic effects in ruminants. Repp, Hale and Burroughs (1955) critically studied urea and four other non-protein nitrogen compounds for their relative toxicities to lambs. Administration of urea, ammonium formate, ammonium acetate and ammonium propionate at a level of about 40 gm urea equivalent per 45.4 kg of body weight resulted in fatal toxicity. In all cases toxicity was associated with large increases in blood ammonia nitrogen, with the critical level being about 1 mg per 100 ml of blood.

Clark and Lombard (1951) reported that sheep which were adapted to a ration of lucerne hay were less susceptible to urea toxicity than the ones adapted to a poor quality grass hay diet. They observed a decrease or entire cessation of ruminal motility as a result of the high rumen pH caused by high ammonia concentration. Coombe _et al._ (1960) observed a marked decrease in rumination time spent by sheep when urea was added to their diets suggesting an inhibitory effect on rumen motility. Like Clark and Lombard (1951) they found that rumen pH had a large influence on this. When sheep were fed hay before being drenched with 25 gm urea, rumen pH did not exceed 6.3 and although the rumen ammonia-N reached 91 mg per 100 ml, rumen movements were not inhibited. However, when fasted for 16 hours before drenching, a dose of 10 gm urea resulted in a rise in rumen pH to 7.3 and complete cessation of rumen movements. When 17 gm ammonium chloride were given instead of urea, the rumen ammonia-N level rose to an even higher value (132 mg per 100 ml) but the pH did not rise above 7.0 and rumen movements were normal.

Russell, Hale and Hubbert, Jr. (1962), in toxicity studies with lambs, found that a much higher level of nitrogen from diammonium phosphate (DAP) was necessary to cause toxicity compared to urea. At a dose level of 15 to 20 units of compound (i.e., 15 to 20 gm urea or urea-equivalent per 45.4 kg body weight), rumen pH of lambs rose from 6.8 to 8.1 in one-half hour with urea and from 6.8 to 7.2 in the case of DAP. In steers dosed with 12 units of either compound, the average blood ammonia-N levels rose from an initial value of 0.13 mg per 100 ml to a peak in one-half hour of 0.71 mg per 100 ml with urea as compared to a rise from an initial level of 0.14 mg per 100 ml to a peak in one-half hour of 0.25 mg per 100 ml with DAP. The above results indicate the influence of the buffering action of phosphate on rumen pH and the absorption rate of ammonia. This influence was demonstrated also by Perez, Warner and Loosli (1967) when fistulated sheep were dosed with urea, urea-phosphate and urea-plus phosphoric acid in single doses of 20 units (20 gm urea or its equivalent in nitrogen per 45.4 kg body weight). The amount of phosphoric acid added to urea was calculated to provide the same amount of phosphate as would be in 20 units of urea-phosphate. The rumen pH rose from an initial value of 7.35 to a peak in 3 hours of 8.30 with the urea treatment. The urea-phosphate and urea-plus phosphoric acid treatments had essentially identical pH trends with each dropping from their initial values of 7.25 and 7.35 to pH 5.9 and 6.35, respectively, at one-half hour postdosing. The urea treatment, which had the highest rumen pH, resulted in the lowest rumen ammonia-N and highest blood ammonia-N values when compared with the two phosphate treatments.

The use of ammoniated phosphates has received increased attention in recent years. Their chemical make-up gives them a dual role as a source of both nitrogen and phosphorus. One such compound is DAP. Russell et al. (1962) found no significant difference in nitrogen retention between urea and DAP in balance trials with lambs when each source provided 31% of the total dietary nitrogen. However, when 60% of the total dietary nitrogen of sheep rations was supplied by urea or DAP, Oltjen et al. (1963) reported less efficient utilization of the nitrogen from diammonium phosphate. These workers also found rations containing DAP to be less palatable to sheep during three growth trials. They indicated that possibly saliva, coming in contact with the feed, resulted in ammonia being released and the feed being refused by the animals. Problems with palatability were reported by Lassiter, Brown and Keyser (1962) when DAP at levels greater than 2% was incorporated into the grain rations of dairy cows. Similar palatability problems were reported by Hale et al. (1962) when 1% of the ration for steers was DAP.

Another ammoniated phosphate which has received only limited attention is monoammonium phosphate (MAP). The only study reported on this compound was that of Reaves, Bush and Stout (1966). They reported that the voluntary feed consumption by nonlactating dairy cows was not significantly different for rations containing no non-protein nitrogen supplement, 1.5% of a mixture of MAP and DAP plus urea (M - DAP + U), 3% M - DAP + U, or 3% DAP. They also measured the amount of ammonia released from reagent-grade DAP, feed-grade DAP, and the M - DAP + U upon contact with bovine saliva for 1 minute with the relative amounts released being 333, 126 and 16 ug/gm, respectively. With respect to each of the materials, there was a definite trend toward increased ammonia release as the pH of the saliva increased.

Inorganic Phosphate Supplements for Ruminants

Phosphorus has long been recognized as an important mineral constituent of living organisms. It is found in every cell of the body with about 80% of the total phosphorus combined with calcium in bones and teeth. Its roles in bone mineralization, buffering systems and intermediary metabolism have prompted extensive research with phosphorus in recent decades. Much of this research resulted in part from its inadequacy under many feeding conditions and its cost when it must be added as a supplement.

There are several inorganic phosphates which are generally used as supplemental phosphorus sources for ruminants. The availability of these various forms has been the basis of considerable research. Early work conducted by Knox and Neale (1937) revealed no differences in growth or reproduction of three groups of thirty grade Hereford heifers each receiving either bone meal, monocalcium or dicalcium phosphate until they were 4-year-old cows. Becker et al. (1944) reported satisfactory results with either defluorinated superphosphate or bone meal as a phosphorus supplement for cattle. They indicated that the superphosphate had to be provided in a salt mixture to insure adequate consumption.

Ammerman et al. (1957), by working with steers and using phosphorus balance and inorganic blood-phosphorus levels as criteria, demonstrated that two commercial dicalcium phosphates, two calcined defluorinated phosphates, and one sample each of bone meal, soft phosphate, and Curacao Island phosphate were of equal value in promoting phosphorus retention and maintaining blood phosphorus levels. The same authors, using lambs, found that dicalcium phosphate and Curacao Island phosphate were well utilized, but soft phosphate and a calcined defluorinated phosphate were poorly utilized. Similar results were reported by Arrington et al. (1962) when dicalcium phosphate, Curacao Island phosphate and defluorinated phosphate were compared in a depletion-repletion type balance study with dairy calves. Wise, Wentworth and Smith (1961), by working with growing calves and using feed intake, weight gain and bone concentration of phosphorus as test criteria, found the phosphorus in defluorinated rock phosphate, Curacao Island phosphate and dicalcium phosphate to be similar in availabilities, with soft phosphate being the least satisfactory supplement used.

Long et al. (1957) conducted two feeding trials with steers to compare the effects of different levels of monosodium phosphate, which is known to be a highly available source of phosphorus, upon certain criteria used as measures of phosphorus nutrition, and to evaluate the relative phosphorus availabilities of steamed bone meal, Curacao Island phosphate and dicalcium phosphate. By using feed intake, weight gain and plasma phosphorus as measures of phosphorus nutrition, these authors reported that no statistically significant differences were found among the different sources of phosphorus, indicating equal availability of phosphorus in the three sources. Lofgreen (1960), by working with mature wethers and the isotope dilution method, found the true digestibilities of phosphorus in dicalcium phosphate, bone meal, soft phosphate and calcium phytate to be 50, 46, 12 and 33%, respectively.

Phosphoric acid as a source of supplemental phosphorus has also been studied. Richardson et al. (1957) indicated that the phosphorus of phosphoric acid was as effective as that of steamed bone meal when the criteria were weight gains and plasma phosphorus levels of heifers maintained on range. Tillman and Brethour (1958a), by working with young steers and using phosphorus balance and digestibility data as criteria, reported the availability of phosphorus supplied by phosphoric acid to be in the same order of magnitude as that supplied by dicalcium phosphate.

The formation of meta- and pyrophosphates during the production of defluorinated phosphate was a problem during the early production of this material. Chicco *et al.* (1965) compared the utilization of inorganic ortho-, meta-, and pyrophosphates using lambs and *in vitro* techniques. Based on both *in vivo* and *in vitro* studies, calcium orthophosphate, sodium orthophosphate and sodium metaphosphate appeared to be equally valuable as sources of phosphorus. Sodium pyrophosphate was somewhat lower than those mentioned in apparent absorption value but equal in solubility and tissue deposition of ^{32}P. Calcium pyrophosphate and calcium metaphosphate were rated low and intermediate, respectively, as sources of available phosphorus.

Tillman and Brethour (1958b) compared the availability of vitreous sodium metaphosphate, acid sodium pyrophosphate and monosodium phosphate for lambs using apparent digestibilities, net retentions, fecal endogenous excretions and true digestibilities of phosphorus as criteria. Acid sodium pyrophosphate was equally as available as monosodium phosphate. The data indicate that the phosphorus of vitreous sodium metaphosphate was absorbed, but was inefficiently utilized and excreted in the feces. Research conducted by Ammerman *et al.* (1957) indicated that the phosphorus of gamma calcium pyrophosphate was almost totally unavailable to sheep while that supplied by vitreous calcium metaphosphate appeared to be about 50% as available as that of monocalcium phosphate. The data indicated that the gamma calcium pyrophosphate was absorbed and increased the plasma inorganic phosphorus, but it was inefficiently utilized and subsequently excreted.

Hall, Baxter and Hobbs (1961) used washed suspensions of rumen microorganisms in a series of studies to determine the effects of adding various levels of phosphorus in different chemical forms upon cellulose digestion. Monosodium orthophosphate, vitreous sodium metaphosphate, acid sodium pyrophosphate and calcium phytate were used. Marked increases in cellulose digestion occurred when levels of 20 to 100 mg of phosphorus per ml of medium from each source were added. Phosphorus in all of the chemical forms studied appeared to be well utilized by rumen bacteria.

Ammerman *et al.* (1965) compared the utilization of inorganic monocalcium orthophosphate, feed grade dicalcium phosphate, defluorinated phosphate and soft phosphate using absorption studies with calves and *in vitro* techniques. Based on *in vitro* studies, monocalcium phosphate was the most available, dicalcium phosphate and defluorinated phosphate were equally available, and soft phosphate was essentially unavailable to rumen microorganisms. *In vivo* results indicated apparent absorption of phosphorus was similar for defluorinated and dicalcium phosphate and both being greater than that for soft phosphate.

Diammonium phosphate is a calcium-free source of phosphorus which also supplies non-protein nitrogen. Its value as a possible source of phosphorus was studied by Oltjen et al. (1963). Extensive metabolism and growth trials with sheep and cattle were conducted by these workers in which diammonium phosphate was incorporated into numerous types of rations to examine its value as a source of nitrogen and phosphorus. In all studies it was found to be a satisfactory source of phosphorus.

Kercher and Paules (1967), working with steers, found no differences between dicalcium phosphate, ammonium polyphosphate, sodium tripolyphosphate and diammonium phosphate as sources of supplemental phosphorus for steer finishing rations. Similar results were reported by Hillis (1968) when no difference was found between diammonium phosphate and monosodium phosphate as a source of supplemental phosphorus for finishing steers and fattening lambs.

Effect of Age on Magnesium Utilization

The development of hypomagnesaemia in calves to the stage at which tetanic convulsions occur has been shown experimentally by Blaxter, Rook and MacDonald (1954) to be a comparatively slow process. In contrast, hypomagnesaemic tetany can develop in the dairy cow and lactating ewe with great rapidity (Rook and Balch, 1958; L'Estrange and Axford, 1963). Wilson (1960) suggested that the increased speed of development of the condition in mature animals may be partly due to its inability to mobilize reserves of magnesium from bone as readily as the young animal.

At critically low levels of magnesium intake the serum magnesium concentration in a mature lactating cow can be rapidly affected by small changes in intake (Rook, 1961). Rook and Storry (1962) stated that in an adult sheep only about 2% of its bone magnesium is available to satisfy physiological needs. In calves maintained on magnesium-deficient diets, Blaxter and Rook (1954) found bone magnesium values of 30% or more below normal but found no measurable decrease in the magnesium concentration in soft tissues.

Further support for the concept that skeletal magnesium in younger animals is mobilized more efficiently than in mature animals is provided by the work of Chicco (1966). Three age levels of sheep (lambs, yearlings and 2-3-year olds) were fed a magnesium-adequate diet which was suddenly replaced by a diet deficient in magnesium. Inappetance appeared more rapidly in the adult animals and the change in feed consumption was shown to be correlated with plasma magnesium concentration.

Smith and Field (1963) reported that after 18 days on a magnesium-deficient diet the mean concentration of magnesium in the femur and mandible had decreased by 9.5 and 13.4%, respectively, in adult rats and 28.2 and 33.3%

in young rats. Martindale and Heaton (1964) found adult rats fed a magnesium deficient diet had a net loss of magnesium from the femur of 17%. They concluded that the skeleton acts as a magnesium reserve but the fraction mobilized in adult rats during magnesium deficiency is smaller than in weanling rats.

Smith (1959b) and Thomas (1959) demonstrated that the percent of bone magnesium in milk-fed calves decreased with age. But it is questionable whether the total reduction of bone magnesium concentration is due to mobilization from the bone or to formation of new bone tissue during a period when the plasma concentration of magnesium is low. Duckworth and Godden (1941) considered that, where the rate of bone growth was maintained, most of the decrease in bone magnesium concentration was attributable to deposition of magnesium-poor bone rather than to net reabsorption of magnesium.

The apparently greater degree of exchange exhibited by the young animal has been related by Robinson and Watson (1955) to the smaller size of the mineral crystals, while Forbes (1959) attributed it to the greater water content of the young bone, which might make magnesium more accessible to circulating body fluids.

The effect of age on magnesium utilization was examined recently by Garces and Evans (1971) with steers ranging in age from 10 to 88 months. They reported magnesium absorption and retention were significantly correlated with magnesium intake and magnesium utilization was similar for all ages.

The increased susceptibility to grass tetany with age has often been attributed to an apparent reduction in the readily available reserves of magnesium. Field (1967), by working with two age groups of sheep which were 2- and 7-years old, respectively, reported a significantly lower dry matter intake by the older group. These results suggest that a reduction with age of the intake of magnesium by grazing animals may be an additional factor contributing to the higher frequency of grass tetany in aged animals.

Magnesium Requirement and Availability

Present estimates indicate about 70% of the total magnesium of the body is present in the skeleton and the normal calcium:magnesium ratio in bones is about 55:1. The magnesium content of bone, muscle and nervous tissue is estimated to be 2 g, 190 mg and 100 mg magnesium/kg fresh weight, respectively (Agricultural Research Council, 1965). The normal level of magnesium in the blood plasma is given as 1.8 mg/100 ml and above, with an upper limit of 3.8 mg/100 ml (Rook and Storry, 1962).

The assessment of dietary requirements of magnesium for maintenance is complicated by the difficulty of estimating the endogenous losses of magnesium from the body. Many researchers have endeavored to estimate these losses by measuring magnesium balance on varying intakes. Walser (1967) states that the basic premises of such an approach are first, that the organism will have the wisdom to reject any magnesium beyond its needs, and second, that negative balance indicates that intake is less than the requirement. However, there is a distinct possibility that no homeostatic mechanism exists in the organism with the primary responsibility of regulating magnesium metabolism. An excessive intake might therefore result in continued positive balance until toxic manifestations ensue. Furthermore, the intake of magnesium is so small in relation to the amount in the body that, if excretion were always proportional to the body content, the establishment of a new steady state following a change in intake would require many months. He further states that negative balance persisting for many weeks following a reduction in intake cannot be accepted as evidence that intake is too low; the preceding intake may have been too high.

Magnesium is lost from the body by three main routes--in the milk, feces and urine. A mean value of 126 mg magnesium/kg has been given as representative for milk (Agricultural Research Council, 1965). Rook and Storry (1962) report a range of published values from 70 to 180 mg/kg, and indicate that no significant fall in the magnesium content of milk occurs when intake of feed or of magnesium is reduced.

Fecal magnesium consists of the unabsorbed portion of the intake and the endogenous magnesium which enters the alimentary tract in the saliva and other digestive secretions. Simesen _et al._ (1962) measured the endogenous excretion of magnesium in milk-fed calves and in cows fed hay and cereals using intravenous injection of ^{28}Mg. Mean values of 3.5 mg and 1.5 mg/kg body weight per day were found for calves and cows, respectively. A tracer study conducted by MacDonald and Care (1959) utilizing a 20-month-old wether resulted in an estimate of 5 mg/kg body weight per day for endogenous fecal magnesium. Field (1959) reported a value of 205 mg per animal per day in sheep by using tracer techniques.

Estimates of endogenous fecal magnesium have also resulted from numerous balance studies. Working with calves Smith (1959a) reported a value of 0.5 mg and 1.2 mg/kg body weight per day for calves 2- to 5-weeks old and 3-months old, respectively. Other values reported are 2 to 4 mg/kg body weight per day in calves (Blaxter and Rook, 1954) and 3 to 5 mg/kg body weight per day in cows (Blaxter and McGill, 1956). Working with 6-month-old lambs Chicco (1966) calculated a value of 2.33 mg/kg body weight per day by extrapolation from the regression of fecal magnesium excretion on magnesium intake.

Urinary excretion of magnesium may be reduced to minimal levels following a decrease in the plasma magnesium concentration. Wilson (1960) suggested that magnesium behaves as a threshold substance appearing in the urine only when the magnesium load filtered by the glomeruli exceeds that reabsorbed by the tubules. Numerous threshold values for blood plasma have been estimated. Storry and Rook (1963) reported threshold values in two cows of 1.5 and 1.8 mg/100 ml of plasma, respectively. Similar values of 1.37 and 1.90 mg/100 ml of plasma were obtained in two lactating ewes by L'Estrange and Axford (1964) by progressively decreasing their magnesium intake 40 mg per day. More recently Chicco (1966), by conducting balance studies with lambs receiving varying levels of dietary magnesium, calculated renal threshold values of between 1.5 mg and 1.6 mg/100 ml of plasma.

Much of the variation in the reported values in the literature of endogenous fecal and urinary magnesium is due partly to the inadequate analytical methods in the past for the quantitative determination of magnesium in biological materials. However, with the recent advent of such analytical methods as atomic absorption spectrophotometry and flame emission spectrophotometry large analytical errors should now be rare.

Although the magnesium requirement of ruminants under various production conditions are still uncertain, there are estimates reported in the literature. Blaxter and McGill (1956) calculated the requirement of an adult cow for maintenance to be about 1.8 gm of magnesium per day, and for production 0.5 to 0.6 gm per 10 lb milk secreted. Assuming an average availability of dietary magnesium of 33%, this indicated a minimum daily requirement of 9 to 11 gm for cows producing 20-30 lb milk daily.

Duncan, Huffman and Robinson (1935) estimated 30 to 40 mg/kg body weight per day was necessary to maintain normal plasma magnesium concentration of milk-fed calves when given various levels of magnesium salts. A similar value of 40 mg/kg body weight was reported for growing calves receiving magnesium salts (Blaxter and Rook, 1954). When the source of dietary magnesium was natural feedingstuffs, however, an intake of 12 to 15 mg/kg body weight was sufficient (Huffman et al., 1941). Thomas (1959) reviewed the available literature and reported a range of from 13 to 46 mg magnesium per kg body weight as being the daily magnesium requirement of calves for maintenance of normal serum or bone magnesium concentrations. Chicco (1966), by feeding various levels of magnesium in the oxide form to 6-month-old lambs, calculated a minimum daily requirement of 4 mg/kg body weight to replace the estimated endogenous magnesium losses from the body. A dietary level of 8 to 10 mg/kg body weight was required, however, to prevent inappetance in yearling sheep (Chicco, 1966).

In estimating the dietary magnesium requirement of an animal consideration must be given to the availability of the dietary magnesium to the animal. It has been shown that availability varies considerably and may be very low in some types of feeds. Field, McCollum and Butler (1958) found the efficiency with which two sheep could utilize the magnesium present in an herbage was 13 and 26%, respectively. Using tracer techniques, McDonald and Care (1959) and Field (1959) found the availability of magnesium in hay for sheep was 26.3 and 25.8%, respectively. The Agricultural Research Council (1965) reported estimates of availability of dietary magnesium for cattle of different ages to be 70% up to 5 weeks, 40% from 5 weeks to 5 months and 20% over 5 months of age.

The absorptive efficiency of magnesium has also been shown to be affected by the magnesium status of the animal. McAleese, Bell and Forbes (1961) found control lambs had apparent absorption values of ^{28}Mg as the chloride of 40 to 50% whereas magnesium deficient lambs had values of 70 to 75%. Magnesium deficient lambs were considered those with serum magnesium values of about 1 mg/100 ml of serum whereas the controls had serum magnesium concentrations of 2 to 2.5 mg/100 ml.

The nutritional relationship between calcium, phosphorus and magnesium in animals has been the object of numerous scientific studies with the exact role each of these ions plays in the metabolism of the other two ions still remaining uncertain. Most of the research on their interactions has been conducted with laboratory animals. However, there is no reason to suppose that the absorption of minerals from the ruminant's intestine should differ basically from that of the non-ruminants. Smith (1969) states that special factors peculiar to ruminants are most likely to be found in the nature of their diet and the modifying effects of the alimentary tract before the abomasum on that diet.

Recent work (Clark and Belanger, 1967) with adult rats receiving adequate dietary levels of calcium and phosphorus and increasing levels of magnesium resulted in increasing absorption, balance and retention of calcium, phosphorus and magnesium with the increasing magnesium intake. Urinary and skeletal content of calcium and magnesium also increased whereas their content of phosphorus decreased. A similar study (Clark, 1968) with adult rats resulted in an increased absorption of calcium with increasing levels of dietary magnesium only when the diet was adequate in calcium content. Urinary calcium was increased, however, irrespective of the dietary level of calcium. The increasing levels of dietary magnesium resulted in increased absorption of phosphorus only when the dietary phosphorus was adequate and the calcium to phosphorus ratio low. Urinary phosphorus was decreased with increasing magnesium intake. Forbes (1963) and Toothill (1963) both reported decreased absorption and serum concentration of magnesium in rats fed high levels of calcium in the diet. An excessive intake of phosphorus has been shown to depress serum magnesium in the guinea pig and rat (O'Dell, Morris and Regan, 1960) and the dog (Bunce, Chiemchaisri and Phillips, 1962).

The interrelationship of calcium, phosphorus and magnesium in ruminants has been examined to a limited extent. A series of such studies was conducted by Chicco (1966) with wether lambs. Increasing levels of dietary calcium resulted in decreased utilization of dietary magnesium when the criteria considered were fecal excretion, bone and serum magnesium. Conversely, there was found to be decreased calcium utilization with increasing dietary levels of magnesium when the criteria considered were fecal excretion and plasma calcium. Bone calcium was not affected by dietary level of magnesium. An increase in calcium intake augmented the urinary loss of magnesium when the lowest level of dietary magnesium was fed, whereas supplemental magnesium lowered the urinary excretion of calcium regardless of the dietary calcium level. Dietary phosphorus appeared to have little effect on magnesium utilization. The fecal excretion of magnesium was slightly increased by supplemental phosphorus, while bone and serum magnesium were not altered. Hjerpe (1968) conducted a balance study with adult wethers receiving a semi-purified diet (by placing in the rumen via a ruminal fistula) supplemented with 0, 0.98 and 9.82 gm of magnesium per animal daily. Wethers receiving supplemental magnesium excreted significantly more urinary calcium and significantly less urinary phosphorus than the non-supplemented controls. The apparent absorption of calcium was slightly decreased by supplemental magnesium whereas apparent absorption of phosphorus was significantly reduced. Wethers receiving either 0.15 or 0.26% dietary magnesium (Dutton and Fontenot, 1967) were found to not differ in calcium balance or serum magnesium concentration. Serum phosphorus levels were found to be less in the wethers fed the low level of magnesium.

Wise, Ordoveza and Barrick (1963) reported a significant reduction in serum magnesium of calves by increasing the dietary phosphorus in the presence of low dietary calcium. The lowest magnesium level occurred at a calcium to phosphorus ratio of 0.4:1 and the highest with the 14.3:1 ratio. Extensive statistical analyses were conducted by Lomba et al. (1968) on data collected from balance studies conducted with 55 different rations fed to 162 dry and lactating cows. Magnesium absorption was found to be enhanced by increasing magnesium and calcium intakes.

Ileal effluent samples from milk-fed, stall-fed and grazing calves had ranges of 34 to 74% of the magnesium and 63 to 93% of the calcium existing in a bound form as measured by it being non-ultrafilterable (Smith and McAllan, 1966). The binding was due to at least two processes; one appeared due to the presence of binding material which appeared to be characteristic of ruminating calves irrespective of diet consumed. This led the authors to conclude that it may have been of microbial origin. The other binding process was believed to be phosphate-dependent. It was later shown by the same authors (Smith and McAllan, 1967), by working with simple inorganic solutions and in vitro techniques, that precipitation of magnesium with phosphate can occur with high concentrations of phosphate in the presence of minimal concentrations of both calcium and ammonia. This precipitation was specifically pH-dependent occurring only at pH of 6.5 and above, which is a characteristic pH of the distal ileum.

The effects of numerous other dietary factors on the availability of magnesium have been studied. The sudden increase in potassium intake which occurs when ruminants first graze spring grass has been considered as a possible contributing factor to the development of hypomagnesaemic tetany. Suttle and Field (1967) found that apparent availability of magnesium to wethers was markedly reduced when the potassium of a hay and concentrate diet was raised to a level found in pastures where tetany had occurred. A similar study was conducted by the same authors (Suttle and Field, 1969) in which ewes fed a diet containing 0.05% magnesium and 4.44% potassium exhibited hypomagnesaemic tetany. This level of potassium had a depressing effect on the concentration of serum magnesium by reducing its apparent absorption and as well by possibly exerting a direct depressing effect on the circulating level of magnesium. High potassium intake in association with high intake levels of _trans_-aconitic acid, which has been found high in certain spring forages, resulted in experimentally induced grass tetany in cattle and the tetany did not occur if either potassium or the acid were received separately (Bohman _et al._, 1969). Lomba _et al._ (1968) reported no significant correlation, however, between the potassium intake, digestibility or utilization, and the fate of dietary magnesium in numerous balance studies conducted with dry and lactating cows. These authors did report a highly significant correlation between fecal magnesium and nitrogen intake with constant magnesium intake. Spring pastures are routinely high in nitrogen content which has long been considered as a contributing factor to the high incidence of hypomagnesaemic tetany in grazing animals during the spring. The binding of magnesium in the ileal effluent samples studied by Smith and McAllan (1966) was increased with increasing concentrations of ammonia when the samples had pH values of 6.5 and above.

CHAPTER III

EFFECT OF LEVELS AND SOURCES OF SUPPLEMENTAL NITROGEN ON VOLUNTARY FEED INTAKE, AVERAGE DAILY GAIN AND BLOOD UREA-N IN STEERS

The use of non-protein nitrogen in ruminant rations increases every year with urea continuing to be the major source. Even though feed formulations have now been devised with which urea may be used safely in relatively high proportions, researchers continue to look for other sources of non-protein nitrogen which may be less toxic and more economical than urea.

One such source of non-protein nitrogen which may be economically competitive with urea is diammonium phosphate (DAP). Interest in DAP was stimulated by its property of being a source of both non-protein nitrogen and supplementary phosphorus. However, problems of voluntary consumption have been reported when DAP is used (Hale et al., 1962; Oltjen et al., 1963; Schaadt et al., 1966; Hillis, 1968). Another dual purpose compound which has recently received attention is monoammonium phosphate (MAP). MAP contains approximately 12% N and 24% P whereas DAP contains approximately 18% N and 21% P. The possibility of MAP being more palatable than DAP has been suggested.

The following four experiments were conducted to compare the effect of urea, DAP and two levels of MAP on feed consumption and blood urea-N in steers.

Procedure and Results

Experiment 1--Effect of Supplemental Nitrogen as Soybean Meal, DAP, Urea and DAP Plus Urea on Voluntary Feed Intake and Average Daily Gain in Steers

Eight steers, four Herefords and four Angus-Hereford crossbreds, were randomly assigned according to breed to four pens of two steers each. Average initial weights of the four outcome groups in kg were 461, 455, 470 and 440. The experimental design was a 4 x 4 Latin square balanced for carry-over effects.

The diets used in this study are shown in Table 1. All diets were calculated to contain the same level of supplemental calcium (0.37%) and no attempt was made to equalize supplemental phosphorus. The diets contained 11.8% crude protein. All steers received the basal diet (diet A) for 8 days at the beginning of each of the four periods to prevent a carry-over effect of treatment. Diets were fed once daily in amounts to give about a 10% weigh back. Experimental diets were fed for 8 days at the end of each period with individual steer weights taken at the beginning and end of the 8-day experimental feeding period.

The data were analyzed statistically by analysis of variance and significant differences between means were

TABLE 1. COMPOSITION OF DIETS

	Diets[1]			
Ingredient	Soybean Meal (A)	DAP (B)	Urea (C)	DAP + Urea (D)
Snapped corn, ground	69.9	72.75	78.13	77.68
Cottonseed hulls	10.0	10.0	10.0	10.0
Alfalfa meal (17% protein)	3.0	3.0	3.0	3.0
Sugarcane molasses	5.0	5.0	5.0	5.0
Soybean meal (50% protein)	10.0	6.19	0.27	0.36
Salt, trace-mineralized[2]	0.6	0.6	0.6	0.6
Calcium phosphate; 17.5% Ca, 23% P	1.0	-	1.0	-
Diammonium phosphate	-	1.5	-	1.5
Urea 281	-	-	1.5	0.9
Ground limestone	0.5	0.96	0.5	0.96
Vitamins A & D[3]	+	+	+	+
	100.00	100.00	100.00	100.00

[1] Diet A provided all supplemental protein as soybean meal; diet B provided 0.269% non-protein nitrogen (NPN) as DAP; diet C provided 0.674% NPN as urea; diet D provided 0.269% NPN as DAP and 0.405% NPN as urea (0.674% total NPN).

[2] Listed minimum analysis in percent: Fe, 0.30; Mn, 0.20; Cu, 0.08; Co, 0.01; Zn, 1.00; I, 0.01; and NaCl, 95.0.

[3] Vitamins added per kg of diet: 2,200 IU vitamin A palmitate and 440 IU vitamin D_2.

determined using Duncan's New Multiple Range Test (Steel and Torrie, 1960).

The average daily feed consumption and average daily gain of steers on the four treatments are shown according to treatment in Table 2. The individual data are presented in Appendix Table 26. Diet C (1.5% urea) was similar to diet A (soybean meal) in acceptability as measured by average daily feed intake (13.97 and 14.38 kg, respectively). The consumption of both diets, however, was significantly greater ($P < .05$) than the average daily feed intakes of 12.02 and 12.52 kg for diets B (1.5% DAP) and D (1.5% DAP plus 0.9% urea), respectively. There were no significant differences in average daily gain among treatments. The large variability that was observed within treatments in average daily gain makes the usefulness of this measurement questionable in such short-term feeding periods.

Experiment 2--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers

Eight steers of British breeding were randomly assigned to four pens of two steers each. The experimental design was a 4 x 4 Latin square balanced for carry-over effects. Two steers were removed from the experiment during the preliminary period due to digestive complications which resulted in two pens having only one steer each. The average initial weight of the six steers used was 312 kg.

TABLE 2. EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION AND AVERAGE WEIGHT GAIN

Item	Treatment			
	Soybean Meal (A)	DAP (B)	Urea (C)	DAP + Urea (D)
Daily feed intake, kg	14.38^a	12.02^b	13.97^a	12.52^b
Daily gain, kg	0.96	0.96	0.16	0.34

[a,b] Means in the same line bearing different superscript are significantly ($P < .05$) different.

The diets used in this study are shown in Table 3. All diets were calculated to contain 0.56% supplemental calcium and phosphorus. The diets contained 11.8% crude protein. All steers received the basal diet (diet A) for 8 days at the beginning of each of the four periods to prevent a carry-over effect of treatment. The experimental diets were fed for 8 days at the end of each period. The diets were fed once daily in amounts to give about a 10% weigh back with individual steer weights taken at the beginning and end of the 8-day experimental feeding periods. At the conclusion of each period the steers were fasted for 12 hours and then allowed to consume ad libitum their respective treatment diets for a period of 2 hours. Blood samples were taken by jugular puncture before feeding and again at the end of the 2-hour period for determination of blood urea-N. The amount of feed consumed by each steer during this 2-hour period was also recorded.

Blood urea-N was determined by the method of Ormsby (1942) with refinements suggested by Richter and Lapoinie (1962). The data were analyzed statistically by analysis of variance and significant differences between means were determined using Duncan's New Multiple Range Test (Steel and Torrie, 1960).

The average daily feed consumption and average daily gain of steers on the four treatments as well as the blood urea-N data are summarized in Table 4. The individual data are presented in Appendix Table 27.

TABLE 3. COMPOSITION OF DIETS

Ingredient	Diets[1] Soybean Meal (A)	 1.50% DAP (B)	 0.75% MAP (C)	 2.30% MAP (D)
Snapped corn, ground	67.34	71.04	68.59	71.21
Cottonseed hulls	10.00	10.00	10.00	10.00
Alfalfa meal (17% protein)	3.00	3.00	3.00	3.00
Sugarcane molasses	5.00	5.00	5.00	5.00
Soybean meal (50% protein)	10.39	6.45	9.10	6.43
Salt, trace-mineralized[2]	0.60	0.60	0.60	0.60
Monosodium phosphate	2.21	0.95	1.50	-
Monoammonium phosphate	-	-	0.75	2.30
Diammonium phosphate	-	1.50	-	-
Ground limestone	1.46	1.46	1.46	1.46
Vitamins A & D[3]	+	+	+	+
	100.00	100.00	100.00	100.00

[1] Diet A provided all supplemental protein as soybean meal; diet B provided 0.269% non-protein nitrogen (NPN) as diammonium phosphate (DAP); diet C provided 0.088% NPN as monoammonium phosphate (MAP); diet D provided 0.269% NPN as MAP.

[2] Listed minimum analysis in percent: Mn, 0.23; I, 0.007; Fe, 0.425; Cu, 0.03; Co, 0.01; S, 0.05; Zn, 0.008; and NaCl, 97.5.

[3] Vitamins added per kg of diet: 2,200 IU vitamin A palmitate and 440 IU vitamin D_2.

TABLE 4. EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)

	Treatment			
Item	Soybean Meal (A)	1.50% DAP (B)	0.75% MAP (C)	2.30% MAP (D)
Daily feed intake, kg	14.49[a]	13.99[ab]	13.55[b]	12.44[c]
Daily gain, kg	1.79[a]	2.98[b]	1.69[a]	1.33[a]
Feed intake, 2 hours (kg)	4.02	3.65	4.06	3.96
Initial BUN[d]	17.00	14.93	15.46	15.96
BUN change, 2 hours[d]	0.36[a]	0.77[ab]	2.32[c]	1.17[b]
BUN change/kg feed consumed[d]	0.12[a]	0.20[a]	0.58[b]	0.29[a]

[a,b,c] Means on the same lines bearing different superscript are significantly ($P < .05$) different.

[d] BUN concentration expressed as mg per 100 ml of whole blood.

Diet B (1.5% DAP) was similar to diet A (soybean meal) in acceptability as measured by average daily feed intake (13.99 and 14.49 kg, respectively). The average daily feed intake of 13.55 kg for diet C (0.75% MAP) was significantly less ($P < .05$) than diet A. Diet D, which contained 2.3% MAP, resulted in an average daily feed intake of 12.44 kg which was significantly less ($P < .05$) than all other treatment diets. Average daily gain during the 8-day experimental periods was significantly greater ($P < .05$) for treatment B (1.50% DAP). Here again the large variability that was observed within treatments makes the usefulness of average daily gain questionable in such short-term feeding periods.

The 12-hour fast at the end of each period followed by _ad libitum_ consumption for 2 hours of their respective treatment diets resulted in similar feed intakes. The blood urea-N concentrations just prior to the 2-hour feeding period were likewise similar. The resulting changes in blood urea-N concentrations following the 2-hour period were similar for diets A (soybean meal) and B (1.5% DAP). The change resulting with diet D (2.3% MAP), however, was significantly greater ($P < .05$) than diet A and the change with diet C (0.75% MAP) was significantly greater ($P < .05$) than with all other treatment diets. When the change in blood urea-N concentration was expressed per kg of feed consumed during the 2-hour period treatment C was significantly greater ($P < .05$) than all other treatments.

Experiment 3--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers

For the present experiment a 4 x 4 Latin square design was again utilized. Four Hereford steers, having an initial average weight of 336 kg, were fed the diets shown in Table 5. The diets used in this experiment were to be replicates of those used in Experiment 2. However, it was not possible to obtain ground snapped corn at the time of this experiment and corn meal along with an increased level of cottonseed hulls were substituted in its place. All other ingredients were the same. This experiment was conducted and analyzed the same as described for Experiment 2.

The average daily feed consumption and average daily gain of steers on the four treatments as well as the blood urea-N data are summarized in Table 6. The individual data are presented in Appendix Table 28. Treatment A (soybean meal), C (0.75% MAP) and D (2.3% MAP) did not differ in acceptability as measured by average daily feed intake. Treatment B, which contained 1.5% diammonium phosphate, was consumed significantly less ($P < .05$) than any other treatment. There were no significant differences in average daily gain among treatments. The 12-hour fast of the steers at the end of each period followed by *ad libitum* consumption for 2 hours of their respective treatment diets resulted in no differences in feed intake between treatments A, C and D. Treatment B, which contained 1.5% diammonium phosphate, was consumed significantly less ($P < .05$) than treatments C and D

TABLE 5. COMPOSITION OF DIETS

Ingredient	Diets[1] Soybean Meal (A)	1.50% DAP (B)	0.75% MAP (C)	2.30% MAP (D)
Corn meal	51.81	55.57	53.09	55.76
Cottonseed hulls	25.00	25.00	25.00	25.00
Alfalfa meal (17% protein)	3.00	3.00	3.00	3.00
Sugarcane molasses	5.00	5.00	5.00	5.00
Soybean meal (50% protein)	10.92	6.92	9.60	6.88
Salt, trace-mineralized[2]	0.60	0.60	0.60	0.60
Monosodium phosphate	2.21	0.95	1.50	-
Monoammonium phosphate	-	-	0.75	2.30
Diammonium phosphate	-	1.50	-	-
Calcium carbonate	1.46	1.46	1.46	1.46
Vitamins A & D[3]	+	+	+	+
	100.00	100.00	100.00	100.00

[1] Diet A provided all supplemental protein as soybean meal; diet B provided 0.269% non-protein nitrogen (NPN) as diammonium phosphate (DAP); diet C provided 0.088% NPN as monoammonium phosphate (MAP); diet D provided 0.269% NPN as MAP.

[2] Listed minimum analysis in percent: Mn, 0.23; I, 0.007; Fe, 0.425; Cu, 0.03; Co, 0.01; S, 0.05; Zn, 0.008; and NaCl, 97.5

[3] Vitamins added per kg of diet: 2,200 IU vitamin A palmitate and 440 IU vitamin D_2.

TABLE 6. EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)

	Treatment			
Item	Soybean Meal (A)	1.50% DAP (B)	0.75% MAP (C)	2.30% MAP (D)
Daily feed intake, kg	8.43^{a}	7.01^{b}	8.71^{a}	8.39^{a}
Daily gain, kg	1.36	0.57	0.37	0.37
Feed intake, 2 hours	2.96^{ab}	2.20^{b}	3.58^{a}	3.47^{a}
Initial BUN[c]	13.31	11.56	12.81	12.21
BUN change, 2 hours[c]	0.09^{ab}	1.25^{a}	-0.06^{b}	1.25^{a}
BUN change/kg feed consumed[c]	0.14^{a}	0.61^{b}	0.00^{a}	0.35^{ab}

[a,b] Means on the same lines bearing different superscript are significantly ($P < .05$) different.

[c] BUN concentration expressed as mg per 100 ml of whole blood.

during this 2-hour period. The blood urea-N concentration prior to the 2-hour feeding period was similar for all treatments and the resulting change in blood urea-N concentration was found to be similar for treatments A, B and D. Treatment C, which contained 0.75% MAP, actually showed an average decrease in BUN concentration, and this was significantly less ($P < .05$) than treatments B and D. When the change in BUN concentration was expressed per kg of feed consumed during the 2-hour period treatments A, C and D were similar. Treatment B, which contained 1.5% DAP, resulted in a significantly greater change ($P < .05$) than treatments A and C, which contained supplemental soybean meal and the lowest level of MAP, respectively.

Experiment 4--Effect of Supplemental Nitrogen as Soybean Meal, DAP and Two Levels of MAP on Voluntary Feed Intake, Average Daily Gain and Blood Urea-N in Steers

The four Hereford steers used in Experiment 3 were again utilized in the present experiment. Following the previous experiment the steers were fed a corn-soybean meal based diet for a period of 9 weeks and had an average weight of 436 kg at the beginning of this experiment. The experimental design was again a 4 x 4 Latin square with the steers receiving the diets shown in Table 7. Diets used in this experiment were mixed weekly whereas diets for the previous experiments were mixed at the beginning of each experiment in adequate quantities for the entire experimental period. The frequent mixing more closely approximates actual feedlot

TABLE 7. COMPOSITION OF DIETS

	Diets[1]			
Ingredient	Soybean Meal (A)	1.50% DAP (B)	0.75% MAP (C)	2.30% MAP (D)
Corn meal	54.36	58.12	55.63	58.29
Cottonseed hulls	25.00	25.00	25.00	25.00
Alfalfa meal (17% protein)	3.00	3.00	3.00	3.00
Corn oil	2.00	2.00	2.00	2.00
Soybean meal (50% protein)	11.37	7.37	10.06	7.35
Salt, trace-mineralized[2]	0.60	0.60	0.60	0.60
Monosodium phosphate	2.21	0.95	1.50	-
Monoammonium phosphate	-	-	0.75	2.30
Diammonium phosphate	-	1.50	-	-
Calcium carbonate	1.46	1.46	1.46	1.46
Vitamins A & D[3]	+	+	+	+
	100.00	100.00	100.00	100.00

[1] Diet A provided all supplemental protein as soybean meal; diet B provided 0.269% non-protein nitrogen (NPN) as diammonium phosphate (DAP); diet C provided 0.088% NPN as monoammonium phosphate (MAP); diet D provided 0.269% NPN as MAP.

[2] Listed minimum analysis in percent: Mn, 0.23; I, 0.007; Fe, 0.425; Cu, 0.03; Co, 0.01; S, 0.05; Zn, 0.008; and NaCl, 97.5.

[3] Vitamins added per kg of diet: 2,200 IU vitamin A palmitate and 440 IU vitamin D_2.

conditions where fresh feed is often mixed daily. Corn oil at a level of 2% of the diets was substituted for the 5% molasses previously used due to the convenience of corn oil under the mixing conditions available. All other ingredients were the same. This experiment was conducted and analyzed the same as described for Experiment 2.

The average daily feed consumption and average daily gain of steers on the four treatments as well as the blood urea-N data are summarized in Table 8. The individual data are presented in Appendix Table 29. There were no significant differences in average daily feed intake among treatments. Treatments C and D (0.75 and 2.3% MAP, respectively) resulted in significantly less ($P < .05$) average daily gain than treatment A (soybean meal). The 12-hour fast at the end of each period followed by ad libitum consumption for 2 hours of their respective treatment diets resulted in similar feed intakes for all diets. The blood urea-N concentrations prior to the 2-hour feeding period were similar for all treatments and the resulting changes following this 2-hour period were found to be similar for treatments A and C. The change with treatment diet D was significantly greater ($P < .05$) than with diets A and C and treatment B resulted in a change significantly greater ($P < .05$) than treatment A. When the change in blood urea-N concentrations were expressed per kg of feed consumed during the 2-hour period treatments A and C were significantly less ($P < .05$) than treatments B and D.

TABLE 8. EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)

	Treatment			
Item	Soybean Meal (A)	1.50% DAP (B)	0.75% MAP (C)	2.30% MAP (D)
Daily feed intake, kg	8.66	8.93	9.23	8.46
Daily gain, kg	1.60^{a}	0.77^{ab}	0.33^{b}	-0.06^{b}
Feed intake, 2 hours	2.44	1.76	2.56	2.56
Initial BUN[c]	14.28	13.51	15.63	13.54
BUN change, 2 hours[c]	0.31^{a}	1.05^{bc}	0.46^{ab}	1.34^{c}
BUN change/kg feed consumed[c]	0.15^{a}	0.60^{b}	0.11^{a}	0.58^{b}

[a,b] Means on the same lines bearing different superscript are significantly ($P < .05$) different.

[c] BUN concentration expressed as mg per 100 ml of whole blood.

Discussion

Diammonium phosphate supplementation has been reported to decrease diet acceptability (Hale et al., 1962; Oltjen et al., 1963; Schaadt et al., 1966; Hillis, 1968). In Experiments 1 and 3 of this series of studies, diets containing 1.5% diammonium phosphate (DAP) were consumed significantly less ($P < .05$) than diets supplemented with soybean meal, urea, or monoammonium phosphate (MAP). This level of DAP, however, did not significantly reduce feed consumption in Experiments 2 and 4.

Levels of 0.75 and 2.3% MAP in Experiments 2, 3 and 4 did not affect feed consumption except in Experiment 2 when the diet containing 2.3% MAP was consumed significantly less ($P < .05$) than the soybean meal and DAP supplemented diets. Reaves et al. (1966) found no appreciable differences in voluntary feed consumption by nonlactating dairy cows when fed rations supplemented with a combination of MAP, DAP and urea or DAP alone.

Although average daily gain was highly variable within treatments and the value of gains recorded on such short-term periods is questionable, it was found that the inclusion of MAP into the experimental diets consistently resulted in a decreased average daily gain.

The amount of feed consumed in a 2-hour period following a 12-hour fast was consistently greater for diets containing MAP compared to those containing 1.5% DAP. The resulting change in blood urea-N was consistently greater for the treatments containing isonitrogenous levels of non-protein nitrogen (1.5% DAP and 2.3% MAP) except in Experiment 2 where the 0.75% MAP treatment resulted in the greatest change in BUN. The same trends existed when the blood urea-N changes were expressed per kg of feed consumed.

A possible contributing factor to the variable results between experiments is the time of year in which each experiment was conducted. Experiments 1, 2, 3 and 4 were conducted during the winter, spring, summer and fall, respectively. Mean rainfall (mm) and mean temperature (C°) for the area during the experimental periods were: (1) 82, 14; (2) 67, 25; (3) 156, 28; (4) 35, 15 (Climatological Data National Summary, 1969-1971). It is possible that the large variations in rainfall and temperatures between experimental periods may have affected the animal performances and the relative outcomes of the separate experiments.

CHAPTER IV

NITROGEN SOURCE AND RUMEN AMMONIA, pH AND BLOOD UREA-N

A major problem resulting in inefficient utilization of non-protein nitrogen sources by ruminants is the rapid release of ammonia. It has been well established that a limiting factor in the utilization of urea is its rapid hydrolysis in the rumen. A reduction in the rate of absorption of the released ammonia would contribute to the efficiency of its utilization by the rumen microbes. Phosphate is thought to buffer rumen pH during urea hydrolysis and therefore minimize ammonia absorption and ammonia wastage.

The following two experiments were conducted to compare the relative rates of release and absorption of ammonia of natural and non-protein nitrogen sources in fistulated wethers.

Procedure and Results

Experiment 1--Effect of Nitrogen Source on Rumen Ammonia, pH and Blood Urea-N

Four fistulated mature wethers ranging in weight from 51.2 to 57.6 kg were utilized in a 4 x 4 Latin square designed experiment balanced for carry-over effects. The sheep were housed in metal metabolism cages and fed the hay-corn based diet shown in Table 9. One kg of this diet was fed once daily and water was supplied ad libitum.

The treatments used in this study consisted of each animal receiving intraruminally 10 gm of nitrogen per 45.4 kg body weight from either soybean meal, urea, diammonium phosphate (DAP) or monoammonium phosphate (MAP). An interval of 6 days between each of the four treatment periods was allowed for the sheep to readjust. On treatment mornings, the nitrogen sources were given in dry form via the fistula approximately 2 hours following consumption of their corn-hay diet. Rumen fluid and jugular blood samples were taken immediately before dosing and at periodic intervals thereafter for determination of rumen pH, rumen ammonia and blood urea. The pH of rumen fluid was determined using a Sargent Model DR pH meter within 1 minute after sampling. Rumen ammonia-N was determined by the phenol nitroprusside-alkaline hypochlorite method of Kaplan et al. (1965). Blood urea-N was determined by the method of Ormsby (1942) with refinements suggested by Richter and Lapoinie (1962). The data were analyzed statistically by analysis of variance and significant differences between means were determined using Duncan's New Multiple Range Test (Steel and Torrie, 1960).

The effect of the four treatments on rumen pH is presented in Table 10 and is presented graphically in Figure 1. The individual data are presented in Appendix

TABLE 9. COMPOSITION OF DIET

Ingredient	%
Bermudagrass hay, ground	70.4
Corn meal	25.0
Corn oil[1]	3.0
Defluorinated phosphate	1.0
Salt, trace-mineralized[2]	0.6
Vitamins A and D[3]	+
	100.0

[1] Stabilized with ethoxyquin.

[2] Listed minimum analysis in percent: Zn, 1.00; Fe, 0.30; Mn, 0.20; S, 0.10; Cu, 0.08; Co, 0.01; and NaCl, 95.00.

[3] 2,200 IU vitamin A palmitate and 440 IU vitamin D_2 added per kg of diet.

TABLE 10. EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON RUMEN pH[a]

Hours After Dosing	Soybean Meal	Urea	DAP	MAP
0	6.82	6.73	6.70	6.77
0.5	6.68^{b}	7.20^{c}	6.94^{d}	6.43^{e}
1	6.66^{b}	7.48^{c}	6.90^{d}	6.45^{e}
2	6.56^{bd}	7.34^{c}	6.79^{d}	6.42^{b}
3	6.52^{b}	7.22^{c}	6.64^{b}	6.41^{b}
4	6.50^{b}	7.13^{c}	6.62^{b}	6.36^{b}
6	6.42^{b}	6.98^{c}	6.51^{b}	6.12^{b}
9	6.39^{bc}	6.71^{c}	6.34^{bc}	6.19^{b}
12	6.48^{bc}	6.54^{c}	6.18^{bd}	6.13^{d}
24	6.85^{b}	6.74^{b}	6.40^{c}	6.34^{c}

[a] All values are means of four periods per treatment.

[b,c,d,e] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

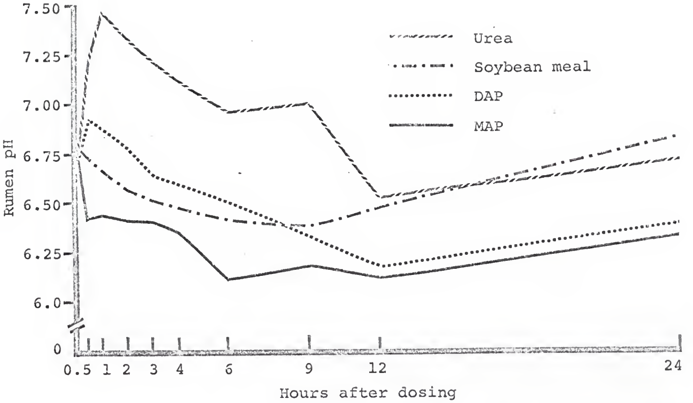

FIGURE 1. EFFECT OF TREATMENTS ON RUMEN pH

Table 30. No significant differences between treatments in predosing ruminal pH were observed. The rumen pH for the urea treatment rose sharply during the first hour to a value of 7.48 and then gradually declined until the twelfth hour to a value slightly lower than the predosing value. The DAP treatment resulted in an initial increase in pH with a maximum value of 6.94 observed at one-half hour postdosing followed by a gradual decline to 6.18 at hour twelve. The MAP treatment resulted in a sharp decrease in pH during the initial 30 minutes followed by a gradual decline to a low of 6.12 at 6 hours postdosing. The DAP treatment remained intermediate to the other two non-protein nitrogen treatments throughout the 24-hour experimental period. The pH in the rumen of sheep receiving soybean meal fell slightly as the day progressed.

Statistical analysis of the rumen pH values at the individual hours revealed a significant $(P < .05)$ difference between all treatments at one-half and one hour postdosing. This difference continued between the non-protein nitrogen treatments through hour two. The urea treatment had significantly $(P < .05)$ higher values of rumen pH than the DAP and MAP treatments for all hours observed except the twelfth.

The effect of treatment on rumen ammonia-N is presented in Table 11 and Figure 2. The individual data are presented in Appendix Table 31. No significant differences existed between treatments in predosing rumen ammonia-N

TABLE 11. EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON RUMEN AMMONIA-N[a]

Hours After Dosing	Mg/100 Ml			
	Soybean Meal	Urea	DAP	MAP
0	15.5	12.8	15.0	16.0
0.5	18.6[b]	77.5[bc]	95.9[bc]	148.4[c]
1	24.2[b]	87.3[bc]	88.5[bc]	118.0[c]
2	26.8[b]	80.2[c]	93.7[c]	107.7[c]
3	29.7[b]	74.2[c]	88.5[c]	93.5[c]
4	34.0[b]	68.2[c]	85.0[c]	93.3[c]
6	29.9[b]	71.9[c]	89.9[c]	78.1[c]
9	23.7[b]	55.4[c]	64.7[c]	64.8[c]
12	22.7[b]	35.7[c]	55.1[d]	56.8[d]
24	20.4[b]	16.6[b]	39.8[c]	42.4[c]

[a] All values are means of four periods per treatment.

[b,c,d] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

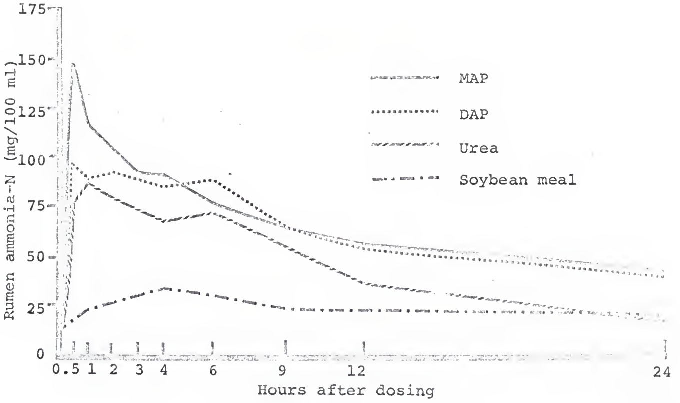

FIGURE 2. EFFECT OF TREATMENTS ON RUMEN AMMONIA-N

concentrations. The highest concentration of ammonia-N (148.4 mg/100 ml) was observed with the MAP treatment at one-half hour postdosing. The DAP treatment had a peak concentration of 95.9 mg/ml also at one-half hour postdosing but changed very little in concentration through hour six. The urea treatment had a peak concentration of 87.3 mg/ml at one hour and exhibited a gradual decline for the remainder of the experimental period. As could be expected, the least change in rumen ammonia-N concentration occurred with the soybean meal treatment.

Statistical analysis of the ammonia-N values at the individual hours revealed no differences between the MAP and DAP treatments and they differed significantly ($P < .05$) from the urea treatment only at hours twelve and twenty-four.

The effect of treatment on blood urea-N is presented in Table 12 and Figure 3. The individual data are presented in Appendix Table 32. No significant difference existed between treatments in predosing blood urea-N concentrations. The urea treatment resulted in the greatest increase in blood urea-N with all non-protein nitrogen treatments reaching a peak concentration at nine hours postdosing. The DAP treatment had a consistently greater concentration of blood urea-N than the MAP treatment from the third hour through the remainder of the sampling period. However, these treatments were not found to be significantly different. The urea treatment had a significantly ($P < .05$)

TABLE 12. EFFECT OF A SINGLE DOSE OF SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE ON BLOOD UREA-N[a]

Hours After Dosing	Mg/100 Ml			
	Soybean Meal	Urea	DAP	MAP
0	16.5	15.0	14.4	15.0
1	17.6^{b}	20.5^{c}	17.3^{b}	17.5^{b}
2	18.0^{b}	22.3^{c}	19.8^{b}	20.4^{bc}
3	19.5^{b}	24.8^{d}	22.5^{cd}	21.9^{bc}
4	20.0^{b}	26.8^{d}	23.7^{c}	23.3^{c}
6	22.0^{b}	31.5^{d}	27.3^{c}	25.0^{c}
9	23.0^{b}	34.8^{d}	30.3^{c}	27.0^{c}
12	23.1^{b}	33.0^{c}	27.4^{b}	26.3^{b}
24	27.3	26.8	25.9	26.0

[a] All values are means of four periods per treatment.

[b,c,d] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

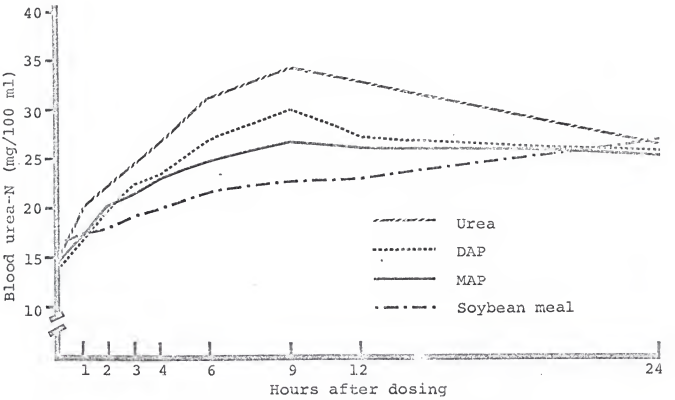

FIGURE 3. EFFECT OF TREATMENTS ON BLOOD UREA-N

greater concentration of blood urea-N than either MAP or DAP for hours four through twelve. None of the treatments differed significantly at hour twenty-four of the sampling period.

Experiment 2--Effect of Nitrogen Source and Supplemental Acid or Base on Rumen Ammonia, pH and Blood Urea-N

The four fistulated wethers used in Experiment 1 were utilized again in the present Latin square experiment. A period of six months was allowed between experiments. The conditions and basal diet for this experiment were the same as those described for Experiment 1. The treatments were urea, urea plus phosphoric acid, monoammonium phosphate (MAP), and MAP plus sodium carbonate. The amount of nitrogen supplied by each treatment was again 10 gm per 45.4 kg body weight.

A preliminary study was conducted with two extra fistulated wethers to determine the amount of phosphoric acid that, when administered simultaneously with 10 gm of nitrogen as urea, would effect a change in rumen pH similar to that which occurs following 10 gm of nitrogen as MAP. This amount of MAP supplies 20.4 gm of phosphorus. However, supplying 20.4 gm of phosphorus as reagent grade phosphoric acid resulted in a reduction in rumen pH to unphysiological levels. It was found that supplying 10 gm of phosphorus as phosphoric acid per 45.4 kg body weight would reduce the rumen pH similar to the reduction with MAP. Similarly, a preliminary study indicated that 21 gm of reagent grade sodium carbonate when administered simultaneously with 10 gm of nitrogen in the form of MAP would affect the rumen pH similar to that which occurs following 10 gm of nitrogen as urea. The designated amounts of phosphoric acid and sodium carbonate were diluted with water to 400 ml for dosing. The treatments receiving only urea or MAP also received 400 ml of water per 45.4 kg body weight. The sampling procedures, chemical and statistical analyses were the same as those described for Experiment 1.

The effect of the four treatments on rumen pH is presented in Table 13 and is presented graphically in Figure 4. The individual data are presented in Appendix Table 33. No significant differences between treatments in predosing ruminal pH were observed. The urea and MAP plus sodium carbonate treatments had pronounced initial increases in rumen pH. The urea treatment reached a peak of 7.52 at one hour postdosing and then gradually declined until the twelfth hour to a value slightly lower than the predosing value. The MAP plus sodium carbonate treatment reached a peak of 7.19 at one-half hour postdosing followed by a fall in pH to 6.78 after only one hour.

The MAP and urea plus phosphoric acid treatments resulted in initial decreases in pH. The urea plus acid treatment reached a value of 5.20 at one-half hour followed by a precipitous rise to a value above the predosing value by the fourth hour. The MAP treatment exhibited a sharp decrease during the initial 30 minutes followed by a

TABLE 13. EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON RUMEN pH[a]

Hours After Dosing	Urea	Urea + Phosphoric Acid	MAP	MAP + Sodium Carbonate
0	6.57	6.54	6.43	6.40
0.5	7.06^{b}	5.20^{c}	6.03^{c}	7.19^{b}
1	7.52^{b}	5.83^{c}	5.99^{c}	6.78^{b}
2	7.40	6.25	6.02	6.67
3	7.07^{b}	6.43^{bc}	5.90^{c}	6.69^{b}
4	6.77^{b}	6.62^{b}	5.87^{c}	6.62^{b}
6	6.66^{b}	6.53^{b}	5.87^{c}	6.54^{b}
9	6.56^{b}	6.41^{b}	5.86^{c}	6.38^{b}
12	6.55^{b}	6.11^{cd}	5.76^{d}	6.27^{bc}
24	6.80^{b}	6.13^{c}	6.04^{c}	6.31^{bc}

[a] All values are means for four periods per treatment.

[b,c,d] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

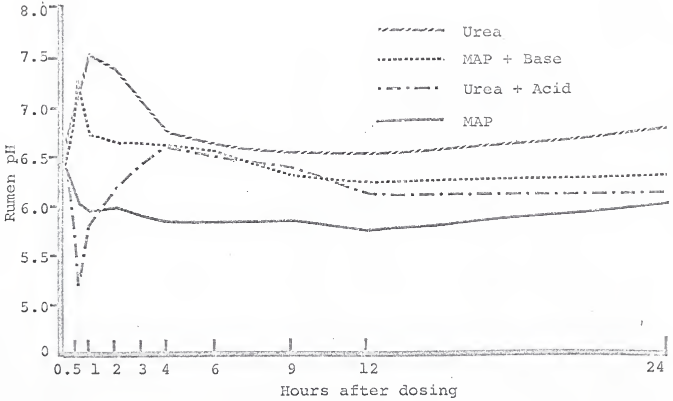

FIGURE 4. EFFECT OF TREATMENTS ON RUMEN pH

gradual decline to a low of 5.76 at twelve hours postdosing. The MAP plus base and urea plus acid treatments showed similar changes in rumen pH from hour four through the remainder of the sampling period.

Statistical analysis of the rumen pH values at the individual hours revealed the urea and MAP plus sodium carbonate treatments to have significantly ($P < .05$) greater pH values than the MAP and urea plus phosphoric acid treatments at one-half and one hour postdosing. The MAP plus base treatment continued significantly ($P < .05$) different from the MAP treatment for hours three through twelve. The urea treatment resulted in a significantly ($P < .05$) higher rumen pH than the MAP treatment for all hours postdosing except the second. This is similar to the results reported in Experiment 1 for the urea and MAP treatments.

The effect of treatment on rumen ammonia-N is presented in Table 14 and Figure 5. The individual data are presented in Appendix Table 34. No significant differences existed between treatments in predosing rumen ammonia-N concentrations. The MAP and MAP plus sodium carbonate treatments exhibited an almost identical pattern in concentration throughout the sampling period. The urea treatment attained its peak concentration earlier than the urea plus phosphoric acid treatment with the latter treatment sustaining a higher concentration throughout the remainder of the sampling period.

TABLE 14. EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON RUMEN AMMONIA-N[a]

	Mg/100 Ml			
Hours After Dosing	Urea	Urea + Phosphoric Acid	MAP	MAP + Sodium Carbonate
0	9.7	10.7	11.0	14.7
0.5	70.7^{b}	34.0^{b}	277.5^{c}	246.5^{c}
1	99.2^{b}	57.5^{d}	200.7^{c}	193.5^{c}
2	112.7^{b}	90.5^{b}	166.5^{c}	158.5^{c}
3	87.7^{b}	103.2^{bc}	138.2^{c}	139.7^{c}
4	73.7^{b}	106.7^{bc}	121.2^{c}	119.7^{c}
6	59.0	95.7	96.7	95.0
9	30.5^{b}	75.2^{c}	82.7^{c}	70.7^{bc}
12	19.2^{b}	57.7^{c}	63.2^{c}	62.0^{c}
24	11.0^{b}	26.0^{bc}	40.2^{c}	40.0^{c}

[a] All values are means for four periods per treatment.

[b,c,d] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

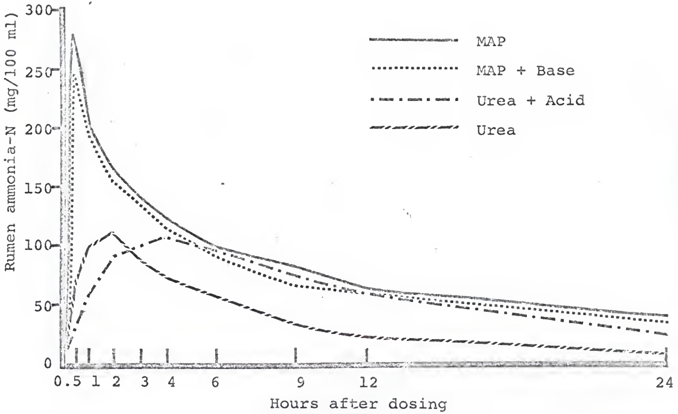

FIGURE 5. EFFECT OF TREATMENTS ON RUMEN AMMONIA-N

Statistical analysis of the ammonia-N values at the individual hours revealed no differences ($P < .05$) between the MAP and MAP plus sodium carbonate treatments. Significant ($P < .05$) differences existed between the urea and urea plus phosphoric acid treatments at hours one, nine and twelve postdosing. The urea and MAP treatments differed significantly ($P < .05$) at all hours postdosing except hour six. Again, this is similar to the results reported in Experiment 1 for the urea and MAP treatments.

The effect of treatment on blood urea-N is presented in Table 15 and Figure 6. The individual data are presented in Appendix Table 35. No significant differences existed between treatments in predosing blood urea-N concentrations. The MAP plus phosphoric acid treatment had a consistently greater concentration of blood urea-N than the urea treatment throughout the sampling period. However, these treatments were not found to differ significantly. The MAP and MAP plus sodium carbonate treatments exhibited similar changes in blood urea-N concentrations. The urea plus phosphoric acid treatment had significantly ($P < .05$) greater concentrations of blood urea-N than the MAP and MAP plus sodium carbonate treatments at hours one, two, four and six postdosing.

Discussion

The results of Experiment 1 suggest that pH of the rumen contents is a controlling factor in the rate of

TABLE 15. EFFECT OF A SINGLE DOSE OF UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE, OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE ON BLOOD UREA-N[a]

	Mg/100 Ml			
Hours After Dosing	Urea	Urea + Phosphoric Acid	MAP	MAP + Sodium Carbonate
0	11.2	12.5	11.0	11.0
1	15.2^{bc}	17.8^{b}	13.8^{c}	12.8^{c}
2	16.7^{bc}	19.6^{b}	14.6^{c}	14.3^{c}
3	18.8	20.7	17.1	15.6
4	20.2^{bc}	21.9^{b}	17.1^{c}	16.6^{c}
6	21.8^{bc}	23.6^{c}	18.5^{b}	18.5^{b}
9	22.5	24.6	19.5	20.1
12	21.7	23.9	20.0	20.3
24	18.9	21.3	18.8	20.6

[a] All values are means for four periods per treatment.

[b,c] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

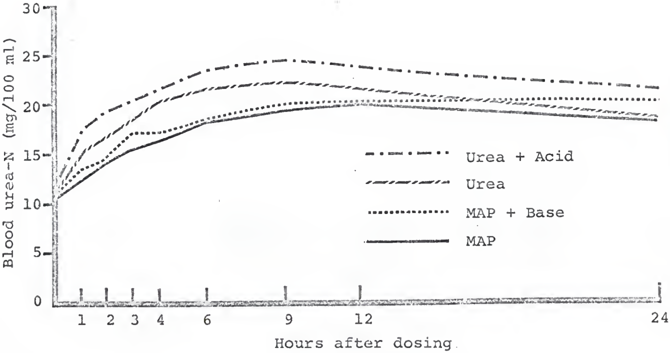

FIGURE 6. EFFECT OF TREATMENTS ON BLOOD UREA-N

ammonia absorption. Of the non-protein nitrogen treatments, urea resulted in the greatest increase in rumen pH, the least increase in rumen ammonia-N concentration, and the greatest increase in blood urea-N. Converse responses resulted with the monoammonium phosphate (MAP) treatment whereas the diammonium phosphate (DAP) treatment was intermediate to the urea and MAP treatments. Urea is hydrolyzed in the rumen to ammonia and carbon dioxide. However, adding 10 gm of nitrogen per 45.5 kg body weight in the form of MAP is also providing the rumen with 20.4 gm of phosphorus, and an isonitrogenous dose of DAP adds 11.5 gm of phosphorus.

It is possible to explain theoretically the significance of rumen pH changes in the absorption of ammonia from the rumen. It is well recognized that the speed of entry of any compound into a cell depends largely upon its molecular volume and its lipoid solubility. It is presumably for these reasons that ammonia (NH_3) enters cells readily and the ammonium ion (NH_4+) slowly. The proportion of NH_3 to NH_4+ present in the rumen contents may be predicted from the Henderson-Hasselbach equation, with the appropriate substitution of the pKa value of NH_3 at a temperature of 40°C:

$$pH = 8.8 + \log \frac{NH_3}{NH_4+}$$

From this equation it can be calculated that the proportion of NH_3 in the rumen will increase rapidly with a rise in pH, and that the proportion of NH_3 to NH_4+ will increase tenfold for a rise of one unit in the pH level. It is therefore to be expected that as the pH rises the rate of absorption of ammonia-N will also rise. Studies supporting this theory have been reported (Coombe _et al._, 1960; Hogan, 1961; Bloomfield _et al._, 1963). All studies showed an increased rate of absorption from the rumen of ammonia-N following an increase in rumen pH.

Experiment 2 was designed to examine further the effect of pH on ammonia-N absorption from the rumen. The MAP plus sodium carbonate treatment resulted in rumen pH values significantly ($P < .05$) greater than the MAP treatment for all samples taken postdosing except for those at hours two and twenty-four. The changes in rumen ammonia-N and blood urea-N concentrations due to these two treatments, however, were essentially identical throughout the sampling period.

The urea plus phosphoric acid treatment resulted in rumen pH values significantly ($P < .05$) less than the urea treatment only for hours one-half, one, twelve and twenty-four postdosing. The difference in pH which occurred early in the period apparently had some effect on rate of ammonia-N absorption from the rumen. The urea plus phosphoric acid treatment had a significantly ($P < .05$) lower rumen ammonia-N concentration at one hour postdosing, and throughout the sampling period exhibited a consistently greater blood urea-N concentration than the urea treatment. This is the reverse of the response that would be expected if the rate of ammonia-N absorption from the rumen were due to rumen pH *per se*.

These results are contrary to those reported by Perez *et al.* (1967) when fistulated sheep which had been fasted 24 hours were dosed per 45.4 kg body weight with either 9.3 gm of nitrogen as urea plus 10.7 gm of phosphorus as phosphoric acid, or with only 9.3 gm of nitrogen as urea. They reported that the urea plus phosphoric acid treatment resulted in a significantly ($P < .01$) lower rumen pH, a significantly ($P < .05$) greater rumen ammonia-N concentration, and a similar trend in blood urea-N concentration.

Although the results of the treatments involving phosphoric acid and sodium bicarbonate do not support the theory that pH is a controlling factor in the rate of ammonia absorption, support is found by comparing the results of the urea and MAP treatments. The urea treatment resulted in a significantly ($P < .05$) higher rumen pH, a significantly ($P < .05$) lower rumen ammonia-N concentration, and a consistently higher blood urea-N concentration than the MAP treatment.

CHAPTER V

THE PHOSPHORUS AVAILABILITY IN MONOAMMONIUM AND MONOSODIUM PHOSPHATES FOR GROWING LAMBS

As previously mentioned in the introduction to Chapter III, considerable interest has been generated in ammoniated phosphates due to their property of being both a source of non-protein nitrogen and phosphorus. The present experiment was conducted to compare the relative biological availabilities of phosphorus in monoammonium and monosodium phosphates in growing lambs.

Procedure and Results

Twenty ewe lambs were used in the present experiment. All lambs were wormed three weeks prior to receiving a phosphorus depletion type diet containing 0.09% phosphorus and 1.64% calcium. This diet differed from the basal diet (Table 16) only by the replacement of 1% corn starch with calcium carbonate. Venous blood samples were taken at the beginning and end of a 2-week period on this low-phosphorus, high-calcium diet. Average initial concentration of plasma phosphorus was 6.5 mg/100 ml and had dropped to an average of 3.5 mg/100 ml at the end of this 2-week phosphorus-depletion period.

TABLE 16. COMPOSITION OF DIETS

	Treatment				
	Basal	Monoammonium Phosphate		Monosodium Phosphate	
Ingredient	0.11% P	0.15% P	0.19% P	0.15% P	0.19% P
Dried citrus pulp	60.00	60.00	60.00	60.00	60.00
Corn starch	13.40	13.23	13.06	13.24	13.08
Bermuda grass hay, ground	13.00	13.00	13.00	13.00	13.00
Gelatin	4.00	4.00	4.00	4.00	4.00
Corn oil[1]	4.00	4.00	4.00	4.00	4.00
Dehydrated alfalfa (17% protein)	3.00	3.00	3.00	3.00	3.00
Urea (281% protein equivalent)	2.00	2.00	2.00	2.00	2.00
Monoammonium phosphate[2]	-	0.17	0.34	-	-
Monosodium phosphate[2]	-	-	-	0.16	0.32
Salt, trace-mineralized[3]	0.60	0.60	0.60	0.60	0.60
Vitamins A and D[4]	+	+	+	+	+
	100.00	100.00	100.00	100.00	100.00
	Percent of Diet				
Chemical analysis[5]					
Phosphorus	0.11	0.15	0.19	0.15	0.19
Calcium	1.27	1.28	1.26	1.25	1.29
Magnesium	0.11	0.11	0.11	0.11	0.11
Crude protein	14.24	14.94	14.50	14.72	14.62

[1] Stabilized with ethoxyquin.

[2] Upon analysis, monoammonium phosphate and monosodium phosphate contained 24.47 and 25.29% phosphorus, respectively.

[3] Listed minimum analysis in percent: Zn, 1.00; Fe, 0.30; Mn, 0.20; S, 0.10; Cu, 0.03; Co, 0.01; and NaCl, 95.00.

[4] 2,200 IU vitamin A palmitate and 440 IU vitamin D_2 added per kg of concentrate.

[5] All values expressed on as-fed basis.

The lambs were randomly allotted according to weight and final plasma phosphorus concentration to the five treatment diets shown in Table 16. The lambs were housed individually in elevated pens. A seedless variety of citrus was used as the source of dried citrus pulp and gelatin was used as a source of preformed protein low in phosphorus. Based on the work of Beeson et al. (1944) and Preston and Pfander (1964), it was felt that a phosphorus level in the supplemented diets of 0.13% would be below the phosphorus requirement for these lambs and a level of 0.17% would be marginal to their requirement. Based upon the analysis of the depletion diet (0.09% P) adequate supplemental phosphorus was added at the expense of corn starch to provide these levels. However, after the experimental diets were mixed the basal diet contained 0.11% total phosphorus and the supplemented diets contained 0.15 and 0.19% phosphorus. Phosphorus, calcium, magnesium and crude protein values for the diets that were obtained by chemical analyses are also shown in Table 16. The high calcium content of these diets resulted from the addition of calcium containing compounds during the processing of the citrus pulp.

The diets were fed once daily in amounts to give about a 10% weigh back. The lambs were weighed every 2 weeks and venous blood samples were obtained weekly. At the end of 9 weeks on the experimental diets all lambs were slaughtered and the right femur removed for analysis. Following drying and ether extraction the volume of each bone was determined by measuring the amount of water displaced by the total bone.

Phosphorus content of feed, plasma and bone was determined by the colorimetric method outlined by Fiske and Subbarow (1925) and determinations for calcium and magnesium were made by atomic absorption spectrophotometry according to the methods recommended by the manufacturer (Anonymous, 1964). The data were analyzed statistically by analysis of variance and significant differences between means were determined using Duncan's New Multiple Range Test (Steel and Torrie, 1960).

The total weight gains, daily feed intake and feed efficiency of lambs on the five treatments are presented in Table 17. Individual data are presented in Appendix Table 36. Two lambs on the 0.19% monosodium phosphate treatment lost 2.5 and 4.5 kg, respectively, during the 9-week experimental period and were excluded from the data analyses.

The total weight gain's on the 0.19% phosphorus-monoammonium phosphate diet were significantly ($P <.05$) greater than those on the 0.15% phosphorus-monosodium phosphate diet and the basal diet. There was an apparent trend of increasing weight gain and feed consumption with increasing levels of total dietary phosphorus and the greatest increases occurred with the monoammonium phosphate supplemented diets.

The level of inorganic phosphorus in plasma is widely used as an index of the state of phosphorus nutrition of an

TABLE 17. AVERAGE INITIAL AND FINAL WEIGHT, DAILY GAIN, FEED INTAKE AND FEED EFFICIENCY OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

	Treatment				
	Basal	Monoammonium Phosphate		Monosodium Phosphate	
Item	0.11% P	0.15% P	0.19% P	0.15% P	0.19% P
Number of animals	4	4	4	4	2
Initial weight, kg	25.96	26.30	26.87	26.64	26.08
Final weight, kg	28.17	30.21	32.99	29.02	31.18
Weight gain, kg	2.21[a]	3.91[ab]	6.12[b]	2.38[a]	5.10[ab]
Daily feed intake, kg	0.62	0.73	0.80	0.66	0.74
Feed/unit gain, kg	16.58[c]	12.45	8.47	23.08[c]	9.38

[a,b] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

[c] No analysis of variance of feed efficiency values was conducted because one animal in each of these treatment groups only maintained its weight.

animal. Table 18 summarizes the plasma phosphorus, calcium and magnesium levels at regular times during the course of the experiment. Individual data for inorganic plasma phosphorus, calcium and magnesium are presented in Appendix Tables 37-39. Lambs receiving the basal diet had lower plasma phosphorus levels throughout the experiment than lambs receiving supplemental phosphorus. There were no significant differences in plasma phosphorus levels between supplemental phosphorus sources or levels. There was a tendency for plasma calcium levels of lambs receiving supplemental phosphorus to decrease following the third week of the experiment. Plasma levels of all minerals analyzed tended to decrease during the final 2 weeks. However, none of these changes were significant.

Table 19 summarizes the data collected from the femurs of lambs on the five treatments. Individual data are presented in Appendix Tables 40-41. There were no significant differences between treatments in weight of dry, fat-free bone nor in bone ash content. These values were numerically greater, however, in the bones of lambs having received the highest supplemental levels of phosphorus. The percent phosphorus of bone ash was highest for lambs having received supplemental phosphorus with the difference between the basal treatment and the treatment containing the highest level of monoammonium phosphate being significant ($P < .05$). The percent calcium and magnesium of bone ash was likewise numerically higher for lambs having received supplemental

TABLE 18. AVERAGE PHOSPHORUS, CALCIUM AND MAGNESIUM LEVELS IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

Phosphorus		Weeks on Trial[ab]				
Source	Percent	0	3	6	9	$\overline{X}$[c]
	Phosphorus (mg/100 ml plasma)					
Basal	0.11	3.60	4.09	4.99	4.54	4.54
Monoammonium	0.15	3.20	4.90	5.92	4.88	5.23
Monoammonium	0.19	3.56	4.90	6.37	5.19	5.49
Monosodium	0.15	3.37	5.50	5.94	5.47	5.64
Monosodium	0.19	4.05	5.79	6.86	4.80	5.82
	Average	3.56	5.04	6.02	4.98	
	Calcium (mg/100 ml plasma)					
Basal	0.11	9.53	10.99	11.27	9.92	10.73
Monoammonium	0.15	10.30	10.85	10.70	9.56	10.37
Monoammonium	0.19	10.38	10.12	10.17	9.39	9.89
Monosodium	0.15	11.04	10.55	9.75	9.50	9.93
Monosodium	0.19	11.01	11.54	10.65	9.59	10.59
	Average	10.45	10.81	10.51	9.59	
	Magnesium (mg/100 ml plasma)					
Basal	0.11	1.95	2.13	2.41	2.27	2.27
Monoammonium	0.15	1.67	2.07	2.22	2.11	2.13
Monoammonium	0.19	1.79	2.05	2.26	2.12	2.14
Monosodium	0.15	1.79	2.08	2.14	2.02	2.08
Monosodium	0.19	2.07	2.47	2.48	2.24	2.40
	Average	1.85	2.16	2.30	2.15	

---

[a] Each value under weeks 3, 6 and 9 is the average of three weekly sampling periods.

[b] Statistical analyses were conducted on the changes in plasma mineral concentrations between the initial concentrations and the averages of every 3 consecutive weeks.

[c] Overall mean of the nine weekly sampling periods.

TABLE 19. AVERAGE MEASUREMENTS AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

	Treatment				
	Basal	Monoammonium Phosphate		Monosodium Phosphate	
Item	0.11% P	0.15% P	0.19% P	0.15% P	0.19% P
Number of animals	4	4	4	4	2
Weight of dry, fat-free bone, gm	45.27	44.38	47.31	44.61	45.93
Ash, % of dry, fat-free bone	64.23	63.79	66.06	65.88	66.28
Phosphorus, % of ash	15.86[a]	16.39[ab]	16.56[b]	16.49[ab]	16.30[ab]
Calcium, % of ash	35.42	35.74	35.78	34.79	35.53
Magnesium, % of ash	0.708[a]	0.733[a]	0.723[a]	0.750[a]	0.859[b]
Volume of dry, fat-free bone, cc[c]	59.96	57.86	61.20	59.09	56.43
Dry, fat-free weight mg/cc[d]	755	767	773	755	814
Ash weight, mg/cc[e]	469	490	506	498	540

[a,b] Means on the same line bearing different superscripts are significantly ($P < .05$) different.

[c] The volume of water displaced by the total, dry-fat-free bone.

[d] Ratio of the total dry-fat-free weight in mg to the volume of water displaced by the total dry-fat-free bone.

[e] Ratio of the total ash weight in mg to the volume of water displaced by the total dry-fat-free bone

phosphorus. The 0.19% monosodium phosphate treatment group, which consisted of two lambs, resulted in significantly ($P < .05$) greater bone ash concentrations of magnesium than the other treatment groups. Expressing the dry, fat-free weights and the ash weights of the bones as mg per cc resulted in the general trend of increasing values with increasing levels of phosphorus.

Discussion

The relative availabilities of the phosphorus in many inorganic phosphorus sources have been evaluated for ruminants using animal growth studies (Long *et al.*, 1957; Wise *et al.*, 1961; Perez *et al.*, 1967). Parameters often measured in such studies are rate of gain, feed intake, inorganic blood phosphorus, and various bone measurements.

The present study was designed to include three levels of phosphorus; two were to be inadequate for normal growth and performance and the third level was to be marginal. All treatment diets used, however, analyzed 0.02% higher in total phosphorus than anticipated. The lowest supplemental phosphorus treatment, which contained 0.15% total phosphorus, was probably marginal with respect to the level of phosphorus needed for normal lamb growth. Beeson *et al.* (1944) found diets containing 0.15% total phosphorus to be adequate for supporting good rate of gain, efficient feed utilization and normal blood phosphorus levels in fattening lambs.

In the present experiment, treatment groups receiving supplemental phosphorus as monoammonium phosphate had numerically greater average daily feed intakes and gains than groups receiving diets supplemented with monosodium phosphate. The plasma and bone analyses, however, did not show consistent trends for either sources of inorganic phosphorus.

Both the 0.15 and 0.19% total phosphorus levels in the supplemented diets were apparently adequate to support normal bone metabolism and a normal serum phosphorus level in the growing lambs. Long et al. (1957) reported linear increases in feed intake, weight gains and serum inorganic phosphorus levels with steers receiving 0.07, 0.11 and 0.15% total dietary phosphorus, whereas a phosphorus level of 0.19% gave results similar to the 0.15% phosphorus treatment.

In spite of the limitation of the present experiment of higher than desired experimental levels of phosphorus in the diets, it can be concluded that the phosphorus in monoammonium phosphate was as well utilized by the growing lambs as that from monosodium phosphate. This result is consistent with studies in which diammonium phosphate (Oltjen et al., 1963; Hillis, 1968), urea-phosphate (Perez et al., 1967), and phosphoric acid (Richardson et al., 1957; Tillman and Brethour, 1958a) have been found to be readily available sources of phosphorus to ruminants.

CHAPTER VI

EFFECT OF AGE AND DIETARY LEVEL OF MAGNESIUM ON MAGNESIUM UTILIZATION BY SHEEP

The availabilities of magnesium stores in the body for mobilization during periods of stress or magnesium deficiency are believed to decrease with age. Wilson (1960) suggested that the greater frequency of hypomagnesaemic tetany in mature animals may be partly due to their decreased ability to mobilize reserves of magnesium from bone as readily as the young animal.

In the present experiment the effect of age on magnesium utilization by sheep was determined using balance techniques and estimates were made of the dietary magnesium requirements for maintenance of the different age groups.

Procedure and Results

Thirty-six Florida native wethers (12 lambs, 12 yearlings and 12 adult sheep) were randomly assigned, within age groups, to three dietary levels of magnesium. The levels were calculated to be 330, 660 and 990 ppm magnesium but the diets fed were found to contain 400, 650 and 950 ppm magnesium, respectively. The supplemental magnesium was supplied as the carbonate by addition of the desired levels to a semi-purified diet (Table 20) at the expense of corn starch. The diet contained 0.20% phosphorus, 0.26% calcium and 11.6% crude protein upon analysis.

All animals had received a corn-hay based diet for the previous 66 days and had been treated twice for intestinal parasites. The animals were housed individually in raised metabolism crates and fed once daily their respective treatment diet at a computed maintenance level. This level was calculated by first determining the amount of metabolizable energy (ME) each sheep would need for maintenance by the formula:

$$1.33 \times 70\ (\mathrm{kg}^{0.75})\ \text{kilocalories}$$

where 70 $\mathrm{kg}^{0.75}$ is an estimate of the energy needed for basal metabolism and the factor 1.33 is an estimate of the unavoidable daily activity of an animal. Values of ME for all ingredients were not available and estimates were made for these. The estimated ME content of the diet was 2.125 kilocalories per kilogram of dry matter and the intake of this diet needed for maintenance was calculated to be 50 gm daily per kg of metabolic body weight ($\mathrm{kg}^{0.75}$) as illustrated in Table 21. This computed maintenance level proved approximately accurate, based upon an average initial weight (41.4 kg) and average final weight (41.8 kg) at the end of 31 days in the metabolism crates. Tap water was provided ad libitum.

A 21-day preliminary feeding period was followed by a 7-day collection period. During the collection period

TABLE 20. COMPOSITION OF EXPERIMENTAL DIET

Ingredient	%
Corn cobs and shucks, ground	35.50
Pure soy protein[1]	7.50
Urea	1.50
Cerelose	18.00
Corn starch	31.62
Corn oil[2]	3.00
Trace mineral mixture[3]	0.24
Salt	0.60
Calcium carbonate (40% calcium)	0.57
Monosodium phosphate (25% phosphorus)	0.47
Vitamins[4]	+
Variables[5]	1.00
	100.00

---

[1] Pure soy protein C-1--Skidmore Enterprises, Cincinnati, Ohio.

[2] Stabilized with ethoxyquin.

[3]

Ingredients	% of Mixture	Mineral added to diet, ppm
Sulfur (Na_2SO_4)	81.37	450
Iron ($FeSO_4$)	11.13	100
Zinc ($ZnCO_3$)	3.93	50
Manganese ($MnCO_3$)	2.14	25
Copper ($CuSO_4$)	1.00	12
Iodine (KI)	0.27	5
Cobalt ($CoCO_3$)	0.16	2
	100.00	

[4] 2,200 IU vitamin A palmitate, 440 IU vitamin D_2 and 11 mg DL alpha tocopherol added per kg of diet.

[5] Variable levels of $MgCO_3$; corn starch was added or removed to adjust to 100%.

TABLE 21. AGE SPECIFICATIONS, BODY WEIGHTS AND FEED OFFERED

Group	No. Animals	Age Specifications	Average Weight, kg		$W^{0.75}$	Daily Feed (gm)	Feed Offered (gm/$W^{0.75}$)
			Initial	Final			
I	11	Lambs (6-12 mos.)	28.8	29.0	12.4	620	50
II	11	Yearlings (1-2 yrs.)	44.0	44.7	17.2	860	50
III	12	Adult sheep (2-3 yrs.)	50.5	50.9	18.9	945	50

total fecal and urinary collections were made at 24-hour intervals. Urine was collected in plastic buckets to which approximately 100 ml of a 25% HCl solution and 10 ml of toluene had been added. Urine volumes were recorded daily and a 10% aliquot was saved for chemical analysis. Feces were collected daily using fecal collection bags. Blood samples were obtained by jugular puncture for 3 consecutive days at the end of the collection period, and the plasma was obtained for each sample for the determination of magnesium, calcium and phosphorus.

The 7-day fecal collections were pooled, thoroughly mixed, and dried to a constant weight in a forced air oven at approximately 60°C. The dried excreta were allowed to gain moisture from the atmosphere for 72 hours, after which they were weighed, ground finely, and an aliquot saved for gross energy, magnesium, calcium and phosphorus determinations.

A sample of the urine as collected was saved for gross energy determinations. The remainder was filtered through Whatman No. 42 filter paper and approximately 100 ml kept for magnesium, calcium and phosphorus determinations.

Energy content of diets, feces and urine was determined by combustion in a Parr oxygen bomb adiabatic calorimeter. Urine samples were prepared by saturating a tared cellulose pellet in a combustion capsule with 5 ml of urine and drying in a vacuum desiccator. Data were corrected for energy value of the cellulose used with each sample portion. Acid and sulfur corrections (Parr Manual No. 130, 1960) were made for all samples combusted. Sulfur was determined by the method outlined by the A.O.A.C. (1960).

Metabolizable energy values were determined as gross energy kilocalories in the diet, minus gross energy kilocalories excreted in the combined urine and feces, minus the estimated gross energy lost in the methane. The gross energy lost in the methane was estimated according to the formula of Blaxter (1962).

Determinations of dry matter and ash in feed and feces and nitrogen in feed were made on duplicate samples according to the methods outlined by the A.O.A.C. (1960). Determinations for magnesium and calcium in feed, feces, urine and plasma were made by atomic absorption spectrophotometry according to the methods recommended by the manufacturer (Anonymous, 1964). Phosphorus content of feed, feces, urine and plasma was determined by the colorimetric method outlined by Fiske and Subbarow (1925). The data were analyzed statistically by regression analysis and analysis of variance with significant differences between means determined by using Duncan's New Multiple Range Test (Steel and Torrie, 1960).

One lamb and one yearling on the lowest dietary magnesium level were removed from the experiment due to inadequate feed consumption. The calculated values for apparent absorption of magnesium, calcium and phosphorus are summarized in Table 22 and values for individual animals are presented in Appendix Tables 42-44. By examining the main

TABLE 22. EFFECT OF AGE AND DIETARY MAGNESIUM ON APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP

Treatment		Apparent Absorption, %		
Age	Magnesium Intake, mg[a]	Mg	Ca	P
Main effects[b]				
Lambs	-	24.56^{d}	10.27^{d}	25.80
Yearlings	-	29.54^{e}	0.85^{de}	10.54
Adult sheep	-	27.26^{de}	-2.30^{e}	28.66
---	20.0	0.43^{x}	7.21	28.96
---	32.5	32.17^{y}	1.87	22.31
---	47.5	44.32^{z}	0.02	15.54
Interaction effects				
Lambs	20.0[c]	-7.51^{d}	23.82^{d}	42.91
Lambs	32.5	30.14^{e}	12.40^{de}	26.38
Lambs	47.5	43.79^{f}	-2.02^{e}	12.40
Yearlings	20.0[c]	3.59^{g}	6.08^{de}	17.48
Yearlings	32.5	32.89^{e}	-4.54^{e}	9.70
Yearlings	47.5	45.64^{f}	2.33^{e}	6.19
Adult sheep	20.0	4.76^{g}	-4.40^{e}	27.09
Adult sheep	32.5	33.47^{e}	-2.24^{e}	30.87
Adult sheep	47.5	43.54^{f}	-0.25^{e}	28.02

[a] Magnesium intake per $kg^{0.75}$ body weight. Five animals had incomplete consumptions of their diets; the amount of magnesium refused was less than 3 mg per $kg^{0.75}$ body weight.

[b] Values for main effects due to age are based on 11 lambs, 11 yearlings and 12 adult sheep; values for main effects due to magnesium intake are based on 10, 12 and 12 animals for the 20.0, 32.5 and 47.5 mg magnesium intake levels, respectively.

[c] Each value based on 3 animals per treatment; all other values for interaction effects are based on 4 animals per treatment.

[d,e,f,g] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .05$) different.

[x,y,z] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .01$) different.

effect due to age there was found to be a greater (P < .05) apparent absorption of magnesium by yearlings than by lambs with adult sheep being intermediate. With increased age there was a linear decrease in apparent absorption of calcium (P < .01) and no significant effect on apparent absorption of phosphorus. Increased dietary magnesium resulted in a linear increase in apparent absorption of magnesium (P < .01). Although the differences were not significant the data did suggest a progressive decrease in apparent absorption of calcium and phosphorus with increased dietary magnesium. No significant age x magnesium intake interactions existed for apparent absorptions of these minerals.

The calculated values for net retention of magnesium, calcium and phosphorus are summarized in Table 23 and values for individual animals are presented in Appendix Tables 45-47. As age of the sheep increased there was no significant effect on net retention of magnesium but there were significant linear decreases in retentions of calcium (P < .01) and phosphorus (P < .01). As magnesium intake increased there were significant linear decreases in net retention of calcium (P < .01) and phosphorus (P < .01). An age x magnesium intake interaction (P < .01) effect was obtained on percent net retention of magnesium. By examining the individual interaction effects it is found that percent net retention of magnesium for lambs at the lowest level of dietary magnesium was significantly (P <.05) less than the values for yearlings

TABLE 23. EFFECT OF AGE AND DIETARY MAGNESIUM ON NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP

Treatment		Net Retention, %		
Age	Magnesium Intake, mg[a]	Mg	Ca	P
Main effects[b]				
Lambs	--	0.81	0.81[d]	8.75[d]
Yearlings	–	0.69	-12.98[e]	-7.17[d]
Adult sheep	–	4.11	-13.41[e]	-8.02[e]
---	20.0	-6.74[d]	1.33[d]	4.28[d]
---	32.5	5.24[e]	-11.94[e]	2.76[de]
---	47.5	5.85[e]	-13.74[e]	-7.37[e]
Interaction effects				
Lambs	20.0[c]	-16.19[d]	17.78[d]	16.99[d]
Lambs	32.5	5.94[ef]	1.32[de]	11.73[de]
Lambs	47.5	8.42[e]	-12.42[ef]	-0.40[def]
Yearlings	20.0[c]	-5.11[g]	1.05[de]	4.02[def]
Yearlings	32.5	4.07[ef]	-21.45[f]	-8.72[f]
Yearlings	47.5	1.67[efg]	-15.03[ef]	-14.02[f]
Adult sheep	20.0	-0.87[fg]	-10.79[ef]	-5.07[ef]
Adult sheep	32.5	5.73[ef]	-15.68[ef]	-11.29[f]
Adult sheep	47.5	7.47[e]	-13.76[ef]	-7.70[ef]

[a] Magnesium intake per $kg^{0.75}$ body weight. Five animals had incomplete consumptions of their diets; the amount of magnesium refused was less than 3 mg per $kg^{0.75}$ body weight.

[b] Values for main effects due to age are based on 11 lambs, 11 yearlings and 12 adult sheep; values for main effects due to magnesium intake are based on 10, 12 and 12 animals for the 20.0, 32.5 and 47.5 mg magnesium intake levels, respectively.

[c] Each value based on 3 animals per treatment; all other values for interaction effects are based on 4 animals per treatment.

[d,e,f,g] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .05$) different.

[x,y,z] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .01$) different.

and adult sheep having received the same magnesium level. However, values of percent net retention of magnesium for lambs were numerically greater than values for yearlings and adult sheep at each of the two higher magnesium intake levels.

The values for urinary excretion as percent of intake of magnesium, calcium and phosphorus are summarized in Table 24 and values for individual animals are presented in Appendix Tables 48-50. There was found to be a significant ($P < .05$) quadratic effect of age on urinary excretion of magnesium when expressed as percent of magnesium intake. Yearlings excreted a significantly ($P < .05$) greater percentage than either lambs or adult sheep. Examination of the interaction effects suggests this difference was due to yearlings which received the highest level of magnesium. They excreted a significantly ($P < .05$) greater percentage in the urine than did lambs or adult sheep receiving the same magnesium level. Age had no significant effect on calcium excretion in the urine but with increased age there was a linear increase in urinary excretion of phosphorus when expressed as percent of intake ($P < .05$). Increased dietary magnesium resulted in linear increases in urinary excretion as percent of intake for magnesium ($P < .01$) and calcium ($P < .01$) with no significant effect on phosphorus.

The values for plasma levels of magnesium, calcium and phosphorus are summarized in Table 25 and values for individual animals are presented in Appendix Tables 51-53.

TABLE 24. EFFECT OF AGE AND DIETARY MAGNESIUM ON URINARY EXCRETION AS PERCENT OF INTAKE OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP

Treatment		Urinary Excretion, % of Intake		
Age	Magnesium Intake, mg[a]	Mg	Ca	P
Main effects[b]				
Lambs	-	24.02^{d}	9.45	17.07^{d}
Yearlings	-	28.93^{e}	13.84	17.74^{d}
Adult sheep	-	23.13^{d}	11.13	36.68^{e}
---	20.0	7.47^{x}	5.89^{d}	24.69
---	32.5	26.90^{y}	13.81^{e}	25.07
---	47.5	38.54^{z}	13.76^{e}	22.94
Interaction effects				
Lambs	20.0^{c}	8.70^{d}	6.06^{d}	25.95
Lambs	32.5	24.18^{e}	11.08^{de}	14.65
Lambs	47.5	35.36^{f}	10.38^{de}	12.82
Yearlings	20.0^{c}	8.70^{d}	5.03^{d}	13.47
Yearlings	32.5	28.81^{ef}	16.91^{e}	18.41
Yearlings	47.5	44.22^{g}	17.38^{e}	20.27
Adult sheep	20.0	5.62^{d}	6.40^{d}	32.16
Adult sheep	32.5	27.73^{e}	13.46^{de}	42.16
Adult sheep	47.5	36.05^{f}	13.53^{de}	35.73

[a] Magnesium intake per $kg^{0.75}$ body weight. Five animals had incomplete consumptions of their diets; the amount of magnesium refused was less than 3 mg per $kg^{0.75}$ body weight.

[b] Values for main effects due to age are based on 11 lambs, 11 yearlings and 12 adult sheep; values for main effects due to magnesium intake are based on 10, 12 and 12 animals for the 20.0, 32.5 and 47.5 mg magnesium intake levels, respectively.

[c] Each value based on 3 animals per treatment; all other values for interaction effects are based on 4 animals per treatment.

[d,e,f,g] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .05$) different.

[x,y,z] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .01$) different.

TABLE 25. EFFECT OF AGE AND DIETARY MAGNESIUM ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS IN SHEEP

Treatment		Plasma Levels, mg/100 ml		
Age	Magnesium Intake, mg[a]	Mg	Ca	P
Main effects[b]				
Lambs	-	1.89	8.80	6.89^{d}
Yearlings	-	1.91	8.84	5.69^{e}
Adult sheep	-	1.85	8.47	5.33^{e}
---	20.0	1.44^{x}	8.59	5.66
---	32.5	1.95^{y}	8.54	6.08
---	47.5	2.18^{z}	8.94	6.06
Interaction effects				
Lambs	20.0[c]	1.47^{d}	8.62^{de}	7.18^{d}
Lambs	32.5	1.94^{e}	8.50^{e}	6.90^{d}
Lambs	47.5	2.16^{f}	9.23^{d}	6.66^{d}
Yearlings	20.0[c]	1.52^{d}	8.88^{de}	5.72^{de}
Yearlings	32.5	1.96^{e}	8.74^{de}	5.91^{de}
Yearlings	47.5	2.16^{f}	8.91^{de}	5.46^{de}
Adult sheep	20.0	1.36^{d}	8.36^{e}	4.48^{e}
Adult sheep	32.5	1.96^{e}	8.39^{e}	5.44^{de}
Adult sheep	47.5	2.22^{f}	8.67^{de}	6.06^{de}

[a] Magnesium intake per $kg^{0.75}$ body weight. Five animals had incomplete consumptions of their diets; the amount of magnesium refused was less than 3 mg per $kg^{0.75}$ body weight.

[b] Values for main effects due to age are based on 11 lambs, 11 yearlings and 12 adult sheep; values for main effects due to magnesium intake are based on 10, 12 and 12 animals for the 20.0, 32.5 and 47.5 mg magnesium intake levels, respectively.

[c] Each value based on 3 animals per treatment; all other values for interaction effects are based on 4 animals per treatment.

[d,e,f,g] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .05$) different.

[x,y,z] Means in same column and within the same main or interaction effects with different superscripts are significantly ($P < .01$) different.

Age did not significantly affect plasma levels of magnesium and calcium but with increasing age there was a linear decrease in plasma phosphorus ($P < .01$). Increased dietary magnesium resulted in a linear increase in plasma magnesium ($P < .01$) but magnesium intake did not significantly affect plasma levels of calcium and phosphorus.

The average value for metabolizable energy of the experimental diet fed was 2,630 kilocalories per kilogram of dry matter with no apparent effects due to age or magnesium level. Fecal magnesium per 1,000 kilocalories of metabolizable energy intake plotted against magnesium intake per 1,000 kilocalories of metabolizable energy for the three age groups of sheep are shown in Figure 7. Individual values are presented in Appendix Table 54. The linear regression equations for the three ages were: lambs, $Y = 0.13X + 170.91$ ($r = 0.60$); yearlings, $Y = 0.25X + 122.25$ ($P < .01$, $r = 0.86$); adult sheep, $Y = 0.26X + 118.44$ ($P < .01$, $r = 0.74$). No significant differences were found between the slopes of the three regression lines.

The point at which the regression lines intersect the ordinate can be considered as the theoretical values for the metabolic fecal magnesium for the three ages. These values were 170.91, 122.25 and 118.44 mg of magnesium per 1,000 kilocalories of metabolizable energy intake per day for lambs, yearlings and adult sheep, respectively.

The relation between fecal magnesium and magnesium intake, both expressed as mg per $kg^{0.75}$ body weight per day,

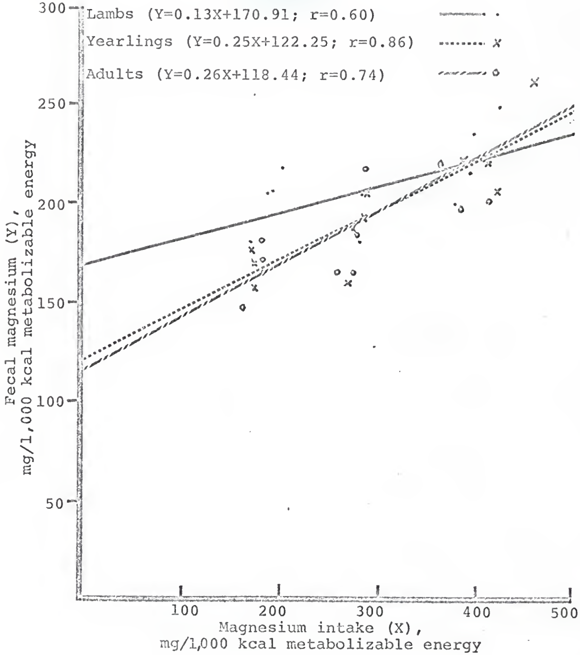

FIGURE 7. RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

is presented in Figure 8 and individual data are presented in Appendix Table 55. The linear regression equations for the three ages were: lambs, $Y = 0.20X + 16.87$ ($P < .01$, $r = 0.89$); yearlings, $Y = 0.25X + 13.95$ ($P < .01$, $r = 0.88$); adult sheep, $Y = 0.30X + 12.30$ ($P < .01$, $r = 0.82$). No significant differences existed between the slopes of the regression lines. The theoretical values for metabolic fecal magnesium obtained by extrapolation to the Y axis were 16.87, 13.95 and 12.30 mg of magnesium per kg$^{0.75}$ body weight per day for lambs, yearlings and adult sheep, respectively.

This same relationship between fecal magnesium and magnesium intake, but expressed as mg per kg body weight per day, is shown in Figure 9 and individual data are presented in Appendix Table 56. The resulting linear regression equations for the three ages were: lambs, $Y = 0.20X + 7.26$ ($P < .01$, $r = 0.87$); yearlings, $Y = 0.24X + 5.48$ ($P < .01$, $r = 0.85$); adult sheep, $Y = 0.33X + 4.25$ ($P < .01$, $r = 0.83$). Again no significant differences existed between slopes of the regression lines. The theoretical values for metabolic fecal magnesium were 7.26, 5.48 and 4.25 mg of magnesium per kg body weight per day for lambs, yearlings and adult sheep, respectively.

Figure 10 presents urinary magnesium plotted against magnesium intake, both expressed as mg per 1,000 kilocalories of metabolizable energy per day, for the three age groups. Individual values are presented in Appendix Table 57. The

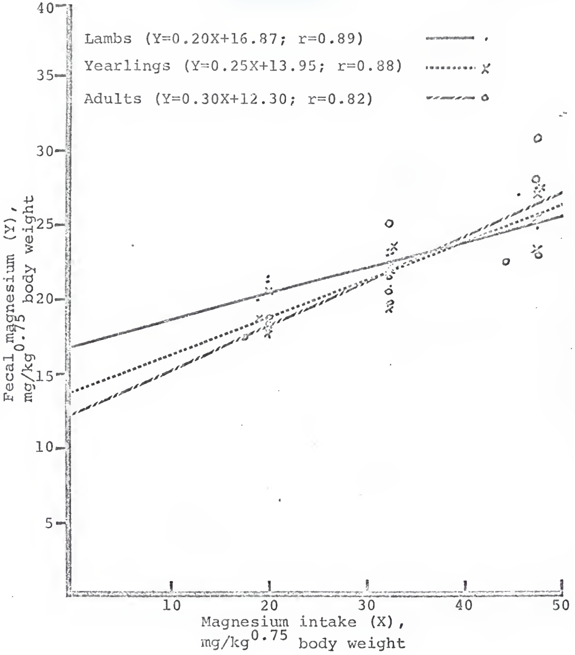

FIGURE 8. RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

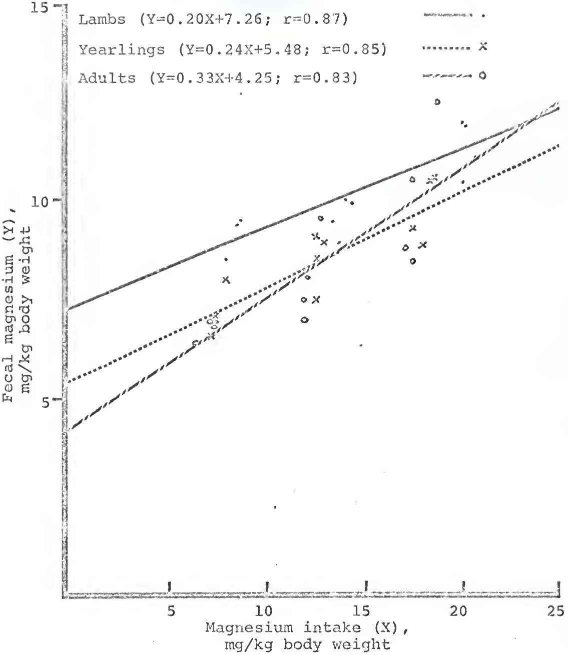

FIGURE 9. RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

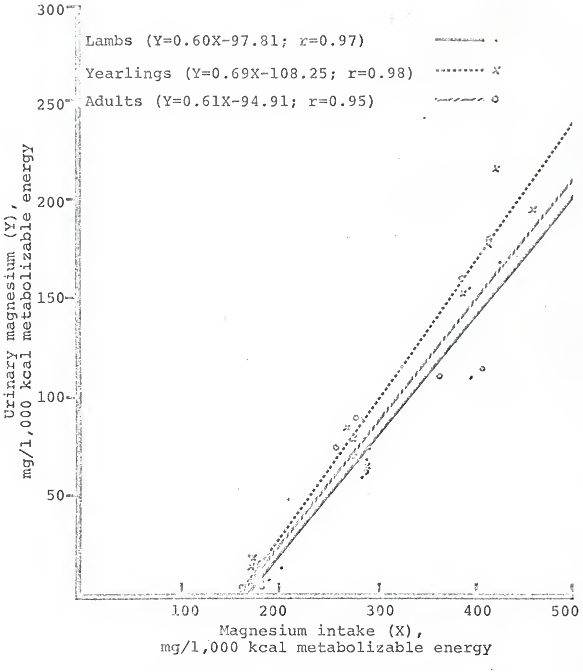

FIGURE 10. RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

linear regression equations for the three ages were: lambs, $Y = 0.60X - 97.81$ ($P < .01$, $r = 0.97$); yearlings, $Y = 0.69X - 108.25$ ($P < .01$, $r = 0.98$); adult sheep, $Y = 0.61X - 94.91$ ($P < .01$, $r = 0.95$). No significant differences were found between the slopes of the three regression lines.

The relation between urinary magnesium and magnesium intake, both expressed as mg per $kg^{0.75}$ body weight per day, is presented in Figure 11 and individual values are presented in Appendix Table 58. The linear regression equations for the three ages were: lambs, $Y = 0.56X - 9.65$ ($P < .01$, $r = 0.97$); yearlings, $Y = 0.70X - 12.63$ ($P < .01$, $r = 0.98$); adult sheep, $Y = 0.57X - 9.63$ ($P < .01$, $r = 0.95$). The slope of the regression line for yearlings was significantly ($P < .05$) greater than the slope of the regression line for lambs indicating that per unit of dietary magnesium intake yearlings excrete a greater percentage in the urine than do lambs when intake and excretion values are expressed per $kg^{0.75}$ body weight per day.

The relation between urinary magnesium and magnesium intake, both expressed as mg per kg body weight per day, is presented in Figure 12 and individual values are presented in Appendix Table 59. The linear regression equations for the three ages were: lambs, $Y = 0.77X - 6.45$ ($P \quad .01$, $r = 0.80$); yearlings, $Y = 0.70X - 4.84$ ($P < .01$, $r = 0.97$); adult sheep, $Y = 0.55X - 3.43$ ($P < .01$, $r = 0.95$). The slope of the regression line for yearlings was significantly ($P < .05$) greater than the slope of the regression line for adult sheep.

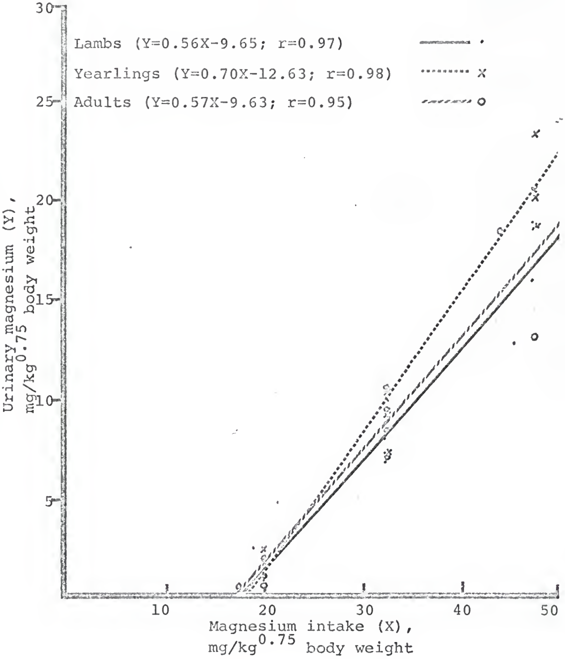

FIGURE 11. RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

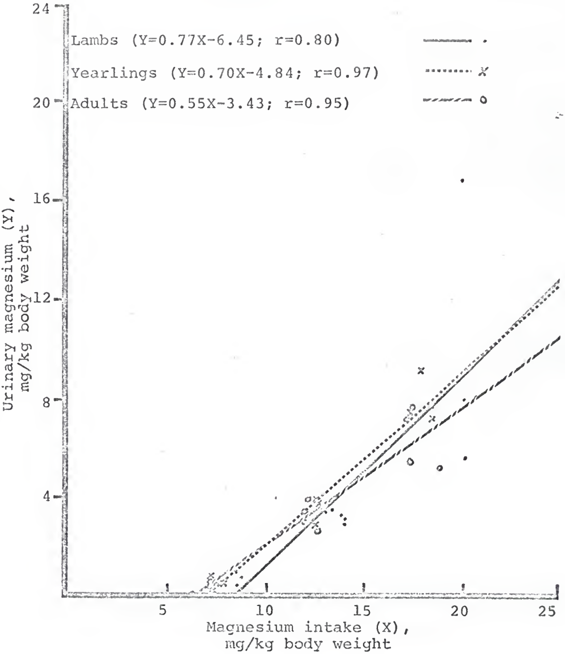

FIGURE 12. RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

Figure 13 presents total magnesium output (fecal plus urinary magnesium) plotted against magnesium intake, both expressed in mg per 1,000 kilocalories of metabolizable energy per day, for the three age groups. Individual values are presented in Appendix Table 60. The linear regression equations for the three ages were: lambs, $Y = 0.73X + 70.49$ ($P < .01$, $r = 0.96$); yearlings, $Y = 0.95X + 11.76$ ($P < .01$, $r = 0.99$); adult sheep, $Y = 0.87X + 22.94$ ($P < .01$, $r = 0.99$). The slope of the regression line for lambs was found to be significantly ($P < .01$) less than the slopes of the regression lines for both yearlings and adult sheep.

The intercept of total magnesium output on the ordinate corresponding to zero intake of magnesium is much lower than the same intercept, as was illustrated in Figure 7, for fecal magnesium (lambs, 70.49 vs. 170.91 mg; yearlings, 11.76 vs. 122.25 mg; adult sheep, 22.94 vs. 118.44 mg, respectively). The lower intercept values on the ordinate are due to the effect of urinary excretion (Figure 10) on this combined relationship. Urinary excretion of magnesium is minimal or zero at low magnesium intake levels, and excretion in the urine will not be appreciable until magnesium intake reaches approximately 150 mg per 1,000 kilocalories of metabolizable energy intake per day.

The minimum dietary requirement of magnesium for maintenance can be estimated by establishing the theoretical value of intake (X) at which the intake and output (Y) are equal. Knowing the slope and the intercept of the regression

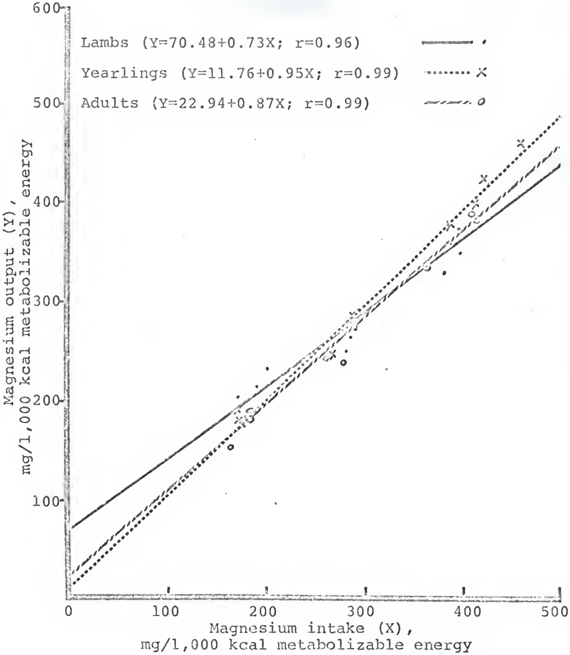

FIGURE 13. RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

lines on the ordinate, the theoretical minimum requirement of magnesium, i.e. the value at which Y and X are equal, is obtained by substituting Y for X in the linear regression equation ($Y = bX + a$) as follows:

$$Y = bY + a \quad \text{or} \quad Y = \frac{a}{1 - b}$$

where b is the slope and a is the ordinate intercept. Solving the equation for each age group of sheep gives a value for the minimum dietary requirement to replace endogenous losses. These values were 261.07, 235.20 and 176.46 mg of magnesium per 1,000 kilocalories of metabolizable energy per day for lambs, yearlings and adult sheep, respectively.

The relation between total magnesium output and magnesium intake, both expressed as mg per $kg^{0.75}$ body weight per day, is presented in Figure 14 and individual values are presented in Appendix Table 61. The linear regression equations for the three ages were: lambs, $Y = 0.75X + 7.21$ ($P < .01$, $r = 0.98$); yearlings, $Y = 0.95X + 1.32$ ($P < .01$, $r = 0.99$); adult sheep, $Y = 0.87X + 2.66$ ($P < .01$, $r = 0.99$). The slope of the regression line for lambs was found to be significantly less than the slope for yearlings ($P < .01$) and adult sheep ($P < .05$). Also the slope of the regression line for adult sheep was significantly ($P < .05$) less than the slope of the line for yearlings.

The minimum dietary requirement for maintenance for each age group, calculated by substituting Y for X in each

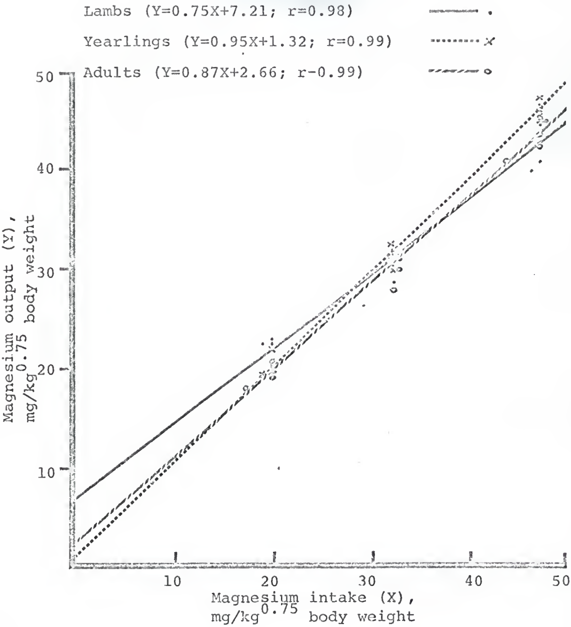

FIGURE 14. RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

of the linear regression equations, was 28.84, 26.40 and 20.46 mg of magnesium per $kg^{0.75}$ body weight per day for lambs, yearlings and adult sheep, respectively.

This same relationship between total magnesium output and magnesium intake, but expressed as mg per kg body weight per day, is shown in Figure 15 and individual data are presented in Appendix Table 62. The resulting linear regression equations for the three ages were: lambs, $Y = 0.75X + 3.14$ ($P < .01$, $r = 0.98$); yearlings, $Y = 0.94X + 0.63$ ($P < .01$, $r = 0.99$); adult sheep, $Y = 0.88X + 0.81$ ($P < .01$, $r = 0.99$). The slope of the regression line for lambs was significantly less than the slope for yearlings ($P < .01$) and adult sheep ($P < .05$). The slopes of the regression lines for yearlings and adult sheep were not significantly different.

The minimum dietary requirement for maintenance for each age group, calculated by substituting Y for X in each of the linear regression equations, was 12.56, 10.50 and 6.75 mg of magnesium per kg body weight per day for lambs, yearlings and adult sheep, respectively.

Figure 16 presents urinary excretion of magnesium per hour plotted against plasma magnesium in mg per 100 ml of plasma for the three age groups of sheep. Individual values are presented in Appendix Table 63. The linear regression equations for the three ages were: lambs, $Y = 9.62X - 13.31$ ($P < .01$, $r = 0.86$); yearlings, $Y = 16.93X - 23.97$ ($P < .01$, $r = 0.77$); adult sheep, $Y = 10.82X - 13.13$ ($P < .01$, $r = 0.83$). There were no significant differences between the slopes of the three regression lines.

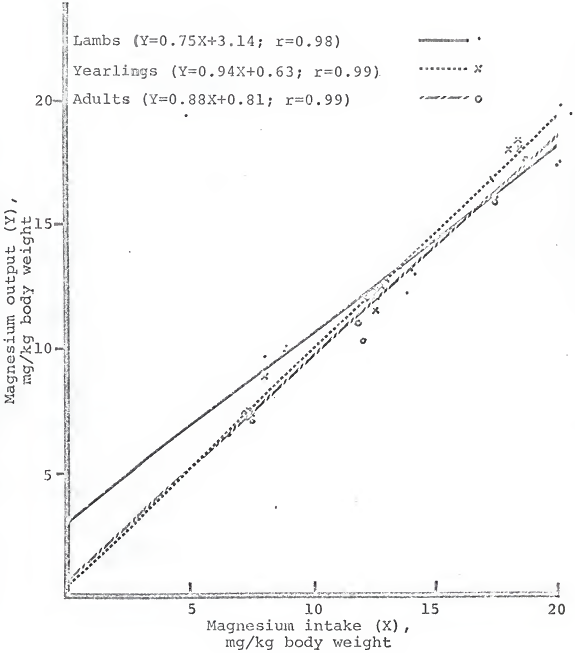

FIGURE 15. RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

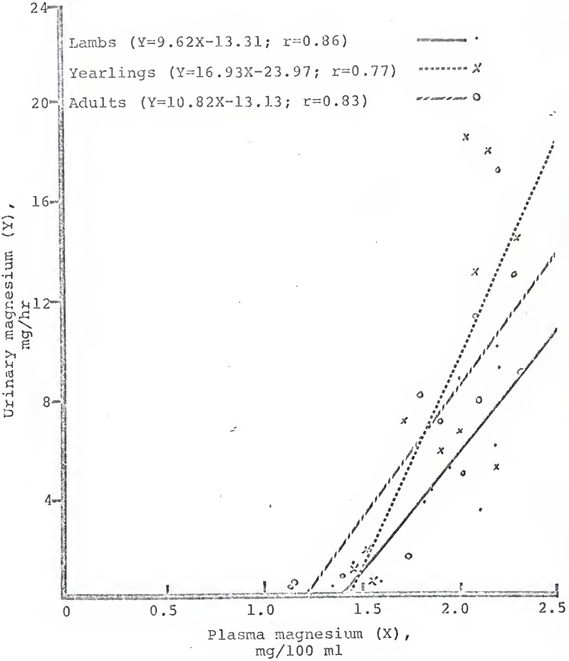

FIGURE 16. RELATION OF URINARY MAGNESIUM TO PLASMA MAGNESIUM

The points at which the regression lines intercept the abscissa is defined as the theoretical magnesium threshold. From the above equations, substituting Y = 0, gives the theoretical concentrations of magnesium in plasma at which magnesium ceases to be excreted in the urine. The calculated threshold values were 1.38, 1.42 and 1.21 mg of magnesium per 100 ml of plasma for lambs, yearlings and adult sheep, respectively.

Discussion

Magnesium utilization in this study, as measured by apparent absorption, net retention, urinary excretion as percent of intake and plasma concentration, was found similar for all ages of sheep. Similar results were reported with steers ranging in age from 10 to 88 months (Garces and Evans, 1971).

The decreased apparent absorption and net retention of calcium with increased age observed in this study are in agreement with evidence presented by Hansard, Comar and Plumlee (1954) and Hansard and Crowder (1957). They demonstrated that as an animal grows older there is less efficient utilization of ingested calcium due to both decreased retention by the tissues and a decrease in membrane permeability for calcium absorption from the gastrointestinal tract. Decreased apparent absorption of calcium with increasing age was recently demonstrated in steers (Garces and Evans, 1971). With increasing age, the retention of phosphorus decreased, plasma inorganic phosphorus decreased and excretion of phosphorus in the urine increased. These findings agree with what might be expected when comparing growing animals with animals having mature skeletal development.

The increase in apparent absorption, net retention, excretion in the urine and plasma concentration of magnesium as magnesium intake increased is similar to results reported by Chicco (1966) with lambs and Clark and Belanger (1967) with rats. Increased dietary magnesium intake resulted in an increase in calcium excretion in the urine and decreased net retention of calcium and phosphorus. A study with adult rats (Clark and Belanger, 1967) receiving adequate calcium and phosphorus and increasing levels of magnesium resulted in increased excretion of calcium in the urine and increased net retention of calcium and phosphorus. Hjerpe (1968) reported increased urinary excretion of calcium and a decrease in urinary phosphorus in mature wethers as their magnesium intakes increased. Chicco (1966) found increased intake of dietary magnesium decreased the urinary excretion of calcium in lambs. The discrepancies that exist between these studies may be due partially to the variation between experiments in treatment levels of magnesium.

For optimal feed efficiency most of the nutrients quantitatively considered in diet formulation should remain in balance with each other. The need for maintaining specified protein-to-calorie ratios in diets for optimum performance has long been recognized and there is increasing interest in considering caloric intake as the fundamental basis for the requirement of most of the known essential nutrients. In the present study the metabolizable energy of the experimental diet, which was fed at a calculated maintenance level, was determined. By expressing the magnesium intake and excretion per 1,000 kilocalories of metabolizable energy intake it was possible to calculate the maintenance requirement of magnesium for the lambs, yearlings and adult sheep and express them on a magnesium-to-calorie basis. The values were found to be 261.07, 235.20 and 176.46 mg of magnesium per 1,000 kilocalories of metabolizable energy intake, respectively. The ratio of magnesium to energy intake would be expected to decrease with maturity due to magnesium being a nutrient which is stored during body growth.

Values reported in the literature for magnesium requirements are expressed as mg needed per day or mg needed per kg body weight. If the requirement is to be expressed on a body weight basis a more desirable expression would be mg per $kg^{0.75}$ body weight. For purpose of illustration, the calculated maintenance requirements from this study for lambs on both the kg and $kg^{0.75}$ body weight basis will be compared. These values were 12.56 and 28.84 mg of magnesium intake per day per kg body weight and $kg^{0.75}$ body weight, respectively. By calculating on each basis the total magnesium intake required per day for lambs of varying weights the difference between the two methods of expressing the requirement can be illustrated. For example, a 20 kg lamb (weight $kg^{0.75} = 9.46$) would require 251.2 mg of magnesium per day on the kg body weight basis and 272.8 mg per day on the $kg^{0.75}$ body weight basis. A 40 kg lamb (weight $kg^{0.75} = 15.91$) would require 502.4 mg of magnesium per day on the kg body weight basis and 458.8 mg per day on the $kg^{0.75}$ body weight basis. It can be observed from these values that the lighter weight lamb requires a greater amount of magnesium per day when expressed per $kg^{0.75}$ body weight as compared to expressing its magnesium requirement per day on the kg body weight basis. The reverse is true for the heavier lamb with the magnesium requirement per day now being greater on the kg body weight basis. If heavier body weights are applied to these same values the requirement per day on the kg body weight basis remains the largest with the difference between the two quantities becoming progressively greater. Therefore, determining the requirement on a $kg^{0.75}$ body weight basis results in a value which corrects for the fact that as an animal becomes larger its metabolic size becomes proportionally less. This same explanation is true for both the yearlings and adult sheep.

As previously mentioned, values reported in the literature for magnesium requirements are expressed as mg needed per day or as mg needed per kg body weight. For this reason the remainder of this discussion will be restricted to the results of this study expressed on a kg body weight basis. The values for metabolic fecal magnesium of 7.26, 5.48 and 4.25 mg of magnesium per kg body weight per day for lambs, yearlings and adult sheep obtained in this study by extrapolation are higher than most reported values. Estimates of 3.5 and 1.5 mg per kg body weight per day were found for calves and cows, respectively (Simesen et al., 1962). A value of 5 mg per kg body weight per day was obtained for a yearling wether using tracer techniques (MacDonald and Care, 1959), and this value is similar to the value obtained for yearlings (5.48 mg) in this study. Other values reported are 2 to 4 mg per kg body weight per day for young calves (Blaxter and Rook, 1954) and 2.33 mg per kg body weight per day for young lambs (Chicco, 1966).

The decreasing values with increasing age for the estimates of metabolic fecal magnesium in this study may reflect a less labile reserve of magnesium in the older animals as compared to the lambs. All animals received the same amount of dietary energy per $kg^{0.75}$ body weight regardless of age or dietary magnesium level. However, by examining the effect of decreasing magnesium intake within each age level (Figure 9) the lambs were apparently able to mobilize magnesium from reserves more readily than the yearlings or adult sheep when dietary magnesium intake became suboptimal resulting in higher endogenous fecal magnesium values for the younger animals. This is supported by the work of Smith and Field (1963) when they reported that after 18 days on a magnesium-deficient diet the concentration of magnesium in the femur and mandible had decreased 9.5 and 13.4%, respectively, in adult rats and 28.2 and 33.3% in young rats. Similar results were also reported by Martindale and Heaton (1964) for adult and weanling rats fed a magnesium-deficient diet.

The variation in fecal loss of magnesium among individual animals (Figure 9) and urinary loss (Figure 12) is in sharp contrast with the uniformity of the data for total magnesium output (fecal plus urinary) for individual animals when plotted against intake (Figure 15). This greater uniformity when the fecal and urinary losses were computed together resulted, in general, from a lower fecal loss being compensated by a greater urinary excretion, and vice versa, for the individual animals. This may indicate individuality even within age groups with reference to their ability to utilize the magnesium.

The calculated requirements of magnesium for maintenance were 12.56, 10.50 and 6.75 mg of magnesium per kg body weight per day for lambs, yearlings and adult sheep, respectively. This greater requirement for young lambs as compared to the older sheep reflects the fact that the metabolic activity per unit body weight is greater in young as compared to older animals and that a greater quantity per unit of body weight is needed in the young animal to maintain normal metabolism.

These requirements of magnesium for maintenance are specific for the conditions of this experiment which include the animals being fed a diet at a calculated maintenance level of energy intake and the magnesium intake being supplied by both the semi-purified diet and supplemental magnesium provided as the carbonate. A requirement of magnesium for maintenance was determined by Chicco (1966) when he fed varying levels of magnesium oxide in a purified diet to young lambs. He reported a value of 4.03 mg per kg body weight as compared to the value in this study of 12.56 mg per kg body weight for lambs. This difference may be due to 4 months difference in the ages of the lambs and the relative availability of magnesium from the different sources.

The calculated magnesium threshold values in this study were 1.38, 1.42 and 1.21 mg of magnesium per 100 ml of plasma for lambs, yearlings and adult sheep, respectively. These values are lower than most reported values. L'Estrange and Axford (1964) reported values of 1.37 and 1.90 mg per 100 ml of plasma in two lactating ewes by progressively decreasing their magnesium intake by increments of 40 mg daily. In a balance study with lambs Chicco (1966) reported renal threshold values of between 1.5 and 1.6 mg per 100 ml of plasma.

CHAPTER VII

GENERAL SUMMARY

Experiments were conducted with steers and sheep to gain information on certain nutritional aspects of non-protein nitrogen, phosphorus and magnesium. The aspects studied involved the influence of source of non-protein nitrogen on feed intake, animal performance and certain ruminal and blood compositional changes, the evaluation of phosphorus in two inorganic phosphate sources, and the influence of age and dietary magnesium level on magnesium utilization. A summary of the results of these studies is presented in the following statements.

Influence of Non-protein Nitrogen Source on Feed Intake, Animal Performance and Blood Urea-N

Diets containing 1.5% diammonium phosphate reduced ($P <.05$) voluntary feed consumption in two of four voluntary feed-intake experiments conducted with steers. A diet containing 2.3% monoammonium phosphate was consumed significantly less ($P < .05$) in one of the experiments. Diets containing the two levels of monoammonium phosphate used (0.75 and 2.3%) resulted in lower average daily gains than diets containing 1.5% diammonium phosphate or supplemental nitrogen as soybean meal. However, the large variations in average daily gains within treatments limit the meaningfulness of gain data from short feeding periods. At the end of each experimental period, steers were fasted 12 hours followed by 2 hours *ad libitum* consumption of their respective treatment diets. The increase in blood urea-N, following the 2-hour feeding period, was greater for treatments containing isonitrogenous levels of non-protein nitrogen (1.5% diammonium phosphate and 2.3% monoammonium phosphate) except in one experiment where 0.75% monoammonium phosphate resulted in the greatest blood urea-N increase.

Effect of Nitrogen Source on Certain Blood and Ruminal Fluid Constituents

Two experiments were conducted with fistulated sheep to examine the effects of natural protein and non-protein nitrogen sources upon rumen ammonia-N, pH and blood urea-N. All nitrogen sources were administered intraruminally as 10 gm of nitrogen per 45.4 kg body weight. Results of the first experiment suggested that pH of the rumen contents was a controlling factor in the rate of ammonia absorption. The urea treatment resulted in the greatest increase in rumen pH, the least increase in rumen ammonia-N concentration and the greatest increase in blood urea-N. Converse responses resulted with monoammonium phosphate and diammonium phosphate was intermediate in effect. Treatments in the second experiment consisted of urea, urea plus phosphoric acid, monoammonium phosphate and monoammonium phosphate plus sodium carbonate. Effects of alkali and acid on rumen pH were of short duration. Blood urea-N values for the urea and urea plus phosphoric acid treatments were similar throughout the sampling period and values for the treatments monoammonium phosphate and monoammonium phosphate plus sodium carbonate were similar.

Relative Availability of Phosphorus in Two Inorganic Phosphorus Sources

In a 9-week growth and slaughter trial with ewe lambs, the phosphorus in monoammonium phosphate was as well utilized as that from monosodium phosphate. The criteria were weight gain, feed intake and feed efficiency, plasma inorganic phosphorus and various bone measurements. The basal diet contained 0.11% phosphorus and the supplemented diets, 0.15 and 0.19% phosphorus.

Influence of Age and Dietary Magnesium Level on Magnesium Utilization

A balance trial was conducted with sheep of three ages (lambs, yearlings and adults) receiving three dietary levels of magnesium and a computed maintenance level of energy intake. With increasing age, the retention of calcium and phosphorus decreased, apparent absorption of calcium decreased, plasma inorganic phosphorus decreased and excretion of calcium in urine increased. These results indicated a decreased need with age for nutrients such as calcium and phosphorus. There was no effect of age on magnesium utilization as measured by any of the above-mentioned criteria. With increasing intakes of dietary magnesium there was a decreased retention of calcium and phosphorus, increased excretion of phosphorus in urine, and increased apparent absorption, retention, urinary excretion and plasma levels of magnesium.

By use of regression analysis (fecal magnesium on magnesium intake) the theoretical values for metabolic fecal magnesium were calculated for lambs, yearlings and adults to be: 170.91, 122.25 and 118.44 mg per 1,000 kilocalories of metabolizable energy (ME) intake per day, respectively; 16.87, 13.95 and 12.30 mg per $kg^{0.75}$ body weight per day, respectively; and 7.26, 5.48 and 4.25 mg per kg body weight per day, respectively. The slopes of the regression lines did not differ between age groups regardless of the basis for expressing the estimated metabolic fecal magnesium. From the regression equations of fecal plus urinary magnesium on magnesium intake for each age group the calculated minimum dietary requirements to replace endogenous losses for lambs, yearlings and adults were: 261.07, 235.20 and 176.46 mg per 1,000 kilocalories of ME intake per day, respectively; 28.84, 26.40 and 20.46 mg per $kg^{0.75}$ body weight per day, respectively; and 12.56, 10.50 and 6.75 mg per kg body weight per day, respectively. These values would be specific for the semi-purified diet fed with supplemental magnesium provided as the carbonate. The slope of the regression line for lambs differed significantly from those for yearlings and adult sheep regardless of the basis for expressing the estimated dietary requirements to replace endogenous losses. The regressions of urinary magnesium on plasma magnesium gave renal threshold values for lambs, yearlings and adults to be: 1.38, 1.42 and 1.21 mg per 100 ml of plasma, respectively.

The estimates for metabolic fecal magnesium and dietary magnesium requirements for the different ages suggest that a more labile magnesium reserve exists in the lamb and that its metabolic activity is greater per unit of body weight.

APPENDIX

TABLE 26. INDIVIDUAL DATA ON EFFECT OF NITROGEN ON FEED CONSUMPTION AND AVERAGE WEIGHT GAIN

Treatment	Period[a]	Daily Feed Intake, kg	Daily Gain, kg
Soybean meal (A)	1	14.9	1.48
	2	15.9	0.80
	3	14.4	0.74
	4	12.4	0.85
DAP (B)	1	15.0	1.82
	2	13.5	2.84
	3	8.9	-0.77
	4	10.8	-0.06
Urea (C)	1	14.3	-0.06
	2	13.4	0.68
	3	13.1	-0.34
	4	15.2	0.34
DAP + Urea (D)	1	11.6	0.63
	2	15.0	0.45
	3	10.0	-0.85
	4	13.5	1.14

[a] Each value the average of 2 animals per pen.

TABLE 27. INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)[a]

Treatment	Periods	Daily Feed Intake, kg	Daily Gain, kg	Feed Intake kg 2 Hours	Initial BUN	BUN Change 2 Hours	BUN Change Per kg Feed Consumed
Soybean meal (A)	1	16.63	1.99	4.83	18.68	0.95	0.22
	2	14.48	2.96	2.49	16.80	0.50	0.25
	3	13.34	1.20	4.54	18.50	-1.25	-0.27
	4	13.50	1.02	4.21	14.00	1.25	0.29
1.50% DAP (B)	1	14.69	1.85	4.16	14.60	1.83	0.43
	2	13.42	5.40	1.77	12.50	0.25	0.14
	3	14.93	1.77	4.27	19.10	0.50	0.12
	4	12.91	2.95	4.41	13.50	0.50	0.11
0.75% MAP (C)	1	12.54	1.25	4.09	13.40	1.60	0.39
	2	15.41	3.75	4.43	17.05	2.58	0.59
	3	12.77	0.80	3.59	15.40	2.10	0.58
	4	13.47	1.48	4.11	16.00	3.00	0.76
2.30% MAP (D)	1	12.32	0.00	4.14	13.80	1.05	0.25
	2	12.26	3.86	1.96	16.75	0.50	0.25
	3	12.40	0.63	4.36	16.75	1.53	0.35
	4	12.80	0.82	5.36	16.55	1.58	0.31

[a] BUN concentration expressed as mg per 100 ml of whole blood.

TABLE 28. INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)[a]

Treatment	Period	Daily Feed Intake, kg	Daily Gain, kg	Feed Intake kg 2 Hours	Initial BUN	BUN Change 2 Hours	BUN change Per kg Feed Consumed
Soybean meal (A)	1	9.33	0.91	4.21	17.00	-1.50	-0.36
	2	6.08	1.08	1.99	9.00	1.00	0.50
	3	8.73	1.93	2.29	11.25	1.25	0.55
	4	9.23	1.54	3.34	16.00	-0.40	-0.12
1.50% DAP	1	5.89	0.80	2.69	12.25	0.50	0.19
	2	7.51	0.57	2.09	12.25	1.50	0.72
	3	7.95	1.36	2.39	11.75	1.50	0.63
	4	6.69	-0.45	1.64	10.00	1.50	0.92
0.75% MAP (C)	1	9.84	0.29	3.89	14.00	0.00	0.00
	2	10.14	1.20	3.59	12.50	0.00	0.00
	3	8.46	0.00	4.44	13.00	-0.50	-0.11
	4	6.39	0.00	2.39	11.75	0.25	0.10
2.30% MAP (D)	1	8.33	1.14	3.69	13.50	0.00	0.00
	2	9.43	0.74	3.19	12.50	1.00	0.31
	3	5.85	-0.29	3.71	8.25	3.50	0.94
	4	9.97	-0.11	3.29	14.60	0.50	0.15

[a] BUN concentration expressed as mg per 100 ml of whole blood.

TABLE 29. INDIVIDUAL DATA ON EFFECT OF SOURCE OF NITROGEN ON FEED CONSUMPTION, AVERAGE WEIGHT GAIN AND BLOOD UREA-N (BUN)[a]

Treatment	Periods	Daily Feed Intake, kg	Daily Gain, kg	Feed Intake kg 2 Hours	Initial BUN	BUN Change 2 Hours	BUN Change Per kg Feed Consumed
Soybean meal (A)	1	10.11	2.95	1.59	13.50	0.60	0.38
	2	9.03	2.16	2.95	14.70	0.15	0.05
	3	7.50	0.40	2.50	12.35	0.00	0.00
	4	8.07	0.91	2.73	13.40	0.50	0.18
1.50% DAP (B)	1	9.91	1.54	1.36	15.00	1.20	0.88
	2	9.20	0.91	1.82	15.50	1.25	0.68
	3	8.49	0.00	2.27	11.95	1.35	0.59
	4	8.18	0.63	1.59	14.80	0.40	0.25
0.75% MAP (C)	1	8.98	-0.23	0.91	19.30	-0.20	-0.22
	2	9.32	0.63	2.95	14.50	0.20	0.07
	3	9.91	0.34	3.64	13.10	0.85	0.23
	4	8.80	0.57	2.73	15.80	1.00	0.37
2.30% MAP (D)	1	10.45	-0.45	2.95	14.30	0.70	0.24
	2	7.47	-0.11	2.73	10.90	0.40	0.14
	3	7.73	-0.11	2.73	13.70	2.15	0.79
	4	8.26	0.45	1.82	15.00	2.10	1.15

[a] BUN concentration expressed as mg per 100 ml of whole blood.

TABLE 30. INDIVIDUAL DATA ON RUMEN pH OF SHEEP DOSED WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE

Period	Sheep No.	Treat-ment	Hours postdosing									
			0	0.5	1	2	3	4	6	9	12	24
1	04	SBM	6.85	6.69	6.65	6.50	6.43	6.46	6.30	6.37	6.46	6.85
	05	DAP	6.64	6.97	6.87	6.59	6.25	6.39	6.30	6.25	6.23	6.51
	06	MAP	6.71	6.27	6.27	6.19	6.18	6.16	5.95	5.91	5.94	6.27
	08	Urea	6.55	7.12	7.58	7.48	7.32	7.22	6.72	6.57	6.64	6.11
2	04	Urea	6.80	7.22	7.46	7.23	7.13	6.93	6.85	6.64	6.23	6.82
	05	SBM	6.75	6.61	6.61	6.64	6.56	6.56	6.55	6.37	6.39	6.93
	06	DAP	6.61	6.71	6.73	6.73	6.70	6.68	6.52	6.31	6.06	6.33
	08	MAP	6.83	6.32	6.49	6.46	6.42	6.42	6.27	6.10	5.91	5.90
3	04	DAP	6.92	7.20	7.13	7.03	6.95	6.75	6.61	6.39	6.10	6.38
	05	MAP	6.61	6.41	6.41	6.34	6.35	6.17	6.14	6.17	6.08	6.51
	06	Urea	6.83	7.12	7.38	7.29	7.21	7.16	6.97	6.65	6.48	6.86
	08	SBM	7.04	6.83	6.81	6.70	6.77	6.75	6.77	6.78	6.68	6.69
4	04	MAP	6.94	6.72	6.63	6.70	6.70	6.70	6.14	6.60	6.62	6.70
	05	Urea	6.77	7.36	7.53	7.36	7.23	7.23	7.40	7.00	6.83	7.20
	06	SBM	6.65	6.60	6.60	6.42	6.35	6.23	6.07	6.05	6.40	6.95
	08	DAP	6.64	6.91	6.87	6.82	6.69	6.67	6.61	6.41	6.35	6.39

TABLE 31. INDIVIDUAL DATA ON RUMEN AMMONIA-N OF SHEEP WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE

Period	Sheep No.	Treat-ment	Hours postdosing									
			0	0.5	1	2	3	4	6	9	12	24
1	04	SBM	19.0	20.5	24.1	28.8	35.0	38.7	30.7	21.7	25.7	30.4
	05	DAP	20.4	153.3	126.8	113.2	100.9	96.2	75.7	53.8	45.7	38.6
	06	MAP	12.5	113.2	81.7	85.4	86.3	83.3	65.5	51.2	46.5	44.1
	08	Urea	11.7	73.1	98.0	89.9	81.3	73.5	59.1	62.2	32.7	13.5
2	04	Urea	15.9	71.8	76.3	62.2	50.5	64.5	80.2	54.9	36.3	26.4
	05	SBM	17.0	21.2	23.0	24.9	28.4	29.0	27.2	19.9	17.0	22.7
	06	DAP	14.6	65.7	106.8	131.1	130.1	122.0	104.1	66.0	59.2	50.3
	08	MAP	15.9	276.5	161.1	132.2	108.5	111.8	88.7	70.2	58.8	42.4
3	04	DAP	11.9	138.6	90.6	93.6	84.6	66.8	69.7	51.1	40.5	25.6
	05	MAP	17.6	113.2	101.0	96.0	84.9	82.4	65.1	56.3	49.8	39.3
	06	Urea	13.3	127.3	119.8	111.1	108.9	77.7	67.4	40.8	24.9	9.2
	08	SBM	12.7	16.8	24.9	31.0	32.0	38.9	33.6	25.8	22.5	16.5
4	04	MAP	18.1	90.8	128.3	117.2	94.1	95.8	93.1	81.5	72.2	43.8
	05	Urea	10.1	37.6	55.1	57.7	55.9	57.1	80.7	63.3	48.8	17.4
	06	SBM	13.3	15.7	24.6	22.5	23.7	29.3	28.0	27.3	25.6	12.1
	08	DAP	13.1	25.8	29.8	36.7	38.3	54.9	110.1	87.7	74.9	44.5

TABLE 32. INDIVIDUAL DATA ON BLOOD UREA-N OF SHEEP DOSED WITH SOYBEAN MEAL, UREA, DIAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE

Period	Sheep No.	Treat-ment	Hours postdosing								
			0	1	2	3	4	6	9	12	24
1	04	SBM	18.5	20.0	20.0	21.5	22.5	24.5	24.0	23.0	25.5
	05	DAP	13.5	15.0	18.5	21.0	22.0	25.5	26.5	25.5	23.5
	06	MAP	13.0	15.0	19.0	20.0	21.0	22.0	22.0	22.0	24.5
	08	Urea	13.5	17.0	18.5	22.0	24.5	28.0	30.5	31.5	24.0
2	04	Urea	16.5	20.0	23.0	25.0	29.0	36.0	39.8	37.5	29.0
	05	SBM	13.0	15.0	15.0	16.5	17.0	20.0	19.2	19.5	24.5
	06	DAP	13.0	16.5	19.5	22.0	23.0	26.5	29.0	27.0	24.0
	08	MAP	13.0	16.0	19.5	21.5	24.0	25.5	27.5	26.5	23.0
3	04	DAP	17.5	20.6	22.5	26.8	28.8	32.9	35.6	28.4	28.5
	05	MAP	15.4	17.5	20.0	21.3	22.8	23.9	25.5	24.6	25.4
	06	Urea	15.4	20.5	23.5	26.6	27.6	33.1	38.9	33.2	26.6
	08	SBM	16.5	16.4	18.1	19.8	21.2	25.2	27.8	28.1	29.4
4	04	MAP	18.4	21.4	23.0	24.8	25.4	28.9	33.0	32.0	31.2
	05	Urea	14.7	24.4	24.3	25.4	25.9	29.0	30.0	29.7	27.6
	06	SBM	18.0	19.0	19.0	20.0	19.5	18.1	21.3	21.8	29.6
	08	DAP	13.7	17.0	18.5	20.0	20.8	24.2	29.9	28.7	27.7

TABLE 33. INDIVIDUAL DATA ON RUMEN pH OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE

Period	Sheep No.	Treatment	Hours postdosing 0	0.5	1	2	3	4	6	9	12	24
1	04	MAP + B[a]	6.51	6.64	6.90	6.62	6.60	6.55	6.52	6.29	6.02	6.18
	05	MAP	6.29	5.86	5.85	5.91	5.85	5.78	5.78	5.80	5.58	5.77
	06	Urea + A[a]	6.77	6.08	6.62	6.67	6.81	6.77	6.61	6.38	6.18	6.28
	08	Urea	6.60	7.21	8.05	8.38	7.71	7.26	7.12	7.09	7.02	6.40
2	04	Urea + A	6.15	4.47	4.91	5.33	5.61	6.23	6.07	6.27	5.77	6.00
	05	MAP + B	6.77	6.96	6.85	6.85	6.87	6.80	6.70	6.63	6.59	6.40
	06	Urea	6.63	6.97	7.56	7.46	7.33	6.95	6.65	6.41	6.33	6.70
	08	MAP	6.52	6.04	6.01	6.10	5.92	6.10	5.98	6.10	5.91	5.95
3	04	MAP	6.27	5.97	5.84	5.88	5.71	5.49	5.63	5.63	5.59	6.31
	05	Urea	6.36	6.74	6.78	6.29	6.10	5.91	5.95	6.06	6.33	7.27
	06	MAP + B	6.04	6.71	6.51	6.42	6.38	6.26	6.20	5.92	5.85	6.08
	08	Urea + A	6.48	4.53	5.51	6.51	6.63	6.76	6.87	6.61	6.25	5.96
4	04	Urea	6.70	7.32	7.70	7.48	7.16	6.99	6.95	6.68	6.52	6.83
	05	Urea + A	6.78	5.75	6.30	6.49	6.69	6.72	6.60	6.41	6.26	6.30
	06	MAP	6.65	6.26	6.27	6.20	6.12	6.12	6.09	5.91	5.98	6.16
	08	MAP + B	6.28	8.45	6.90	6.82	6.94	6.88	6.75	6.68	6.64	6.59

[a] MAP + B and Urea + A stand for MAP plus sodium carbonate and urea plus phosphoric acid, respectively.

TABLE 34. INDIVIDUAL DATA ON RUMEN AMMONIA-N OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE AND MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE

Period	Sheep No.	Treat-ment	Hours postdosing									
			0	0.5	1	2	3	4	6	9	12	24
1	04	MAP + B[a]	28	392	226	178	156	126	93	62	48	35
	05	MAP	13	464	300	230	197	170	141	109	91	62
	06	Urea + A[a]	13	65	122	160	144	103	86	57	39	11
	08	Urea	7	61	121	149	107	79	72	47	31	11
2	04	Urea + A	12	21	29	47	64	91	116	114	92	48
	05	MAP + B	4	204	192	150	119	93	95	73	68	38
	06	Urea	14	110	119	136	106	85	61	32	17	16
	08	MAP	13	272	156	198	150	128	104	111	63	34
3	04	MAP	8	174	162	94	87	83	66	50	45	28
	05	Urea	3	45	71	76	56	55	29	8	6	9
	06	MAP + B	15	230	184	156	129	119	101	81	74	45
	08	Urea + A	8	16	20	51	72	99	88	63	50	24
4	04	Urea	15	67	86	90	82	76	74	35	23	8
	05	Urea + A	10	34	59	104	133	134	93	67	50	21
	06	MAP	10	200	185	144	119	104	76	61	54	37
	08	MAP + B	12	160	172	150	155	141	91	67	58	42

[a] MAP + B and Urea + A stand for MAP plus sodium carbonate and urea plus phosphoric acid, respectively.

TABLE 35. INDIVIDUAL DATA ON BLOOD UREA-N OF SHEEP DOSED WITH UREA, UREA PLUS PHOSPHORIC ACID, MONOAMMONIUM PHOSPHATE OR MONOAMMONIUM PHOSPHATE PLUS SODIUM CARBONATE

Period	Sheep No.	Treatment	Hours postdosing								
			0	1	2	3	4	6	9	12	24
1	04	MAP + B[a]	13.8	15.8	17.5	19.3	19.3	19.3	19.3	20.2	22.8
	05	MAP	6.5	10.4	11.3	12.4	13.3	14.7	17.2	17.7	15.4
	06	Urea + A[a]	13.8	16.4	19.7	20.7	22.3	23.6	24.5	24.3	20.2
	08	Urea	7.2	12.2	13.8	15.2	17.5	19.8	21.8	23.8	20.4
2	04	Urea + A	12.5	17.7	18.8	19.6	20.2	21.8	22.3	20.2	23.4
	05	MAP + B	7.3	10.8	12.6	13.9	15.8	19.7	22.7	21.6	19.0
	06	Urea	15.2	17.8	20.3	23.8	23.4	25.4	25.5	22.7	20.2
	08	MAP	11.2	13.0	13.3	14.8	16.8	18.4	20.7	21.3	19.0
3	04	MAP	14.4	16.9	16.3	17.2	17.5	18.3	17.5	17.8	18.7
	05	Urea	7.6	14.3	14.3	16.2	16.9	17.2	15.2	13.2	16.3
	06	MAP + B	12.8	13.3	13.7	14.8	15.4	17.6	18.3	17.8	19.1
	08	Urea + A	12.4	19.8	21.2	22.6	23.3	23.3	22.6	23.0	19.4
4	04	Urea	14.8	16.6	18.5	20.2	23.0	25.0	27.5	27.3	18.8
	05	Urea + A	11.3	17.6	18.7	20.2	21.8	26.0	29.3	28.2	22.4
	06	MAP	12.0	15.2	17.6	19.4	21.0	22.8	22.8	23.4	22.4
	08	MAP + B	10.4	11.4	13.5	14.7	16.2	17.6	20.2	21.8	21.7

[a] MAP + B and Urea + A stand for MAP plus sodium carbonate and urea plus phosphoric acid, respectively.

TABLE 36. INDIVIDUAL DATA ON DAILY GAIN, FEED INTAKE AND FEED EFFICIENCY OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

Phosphorus, Source and Level	Lamb No.	Weight Gain, kg	Daily Feed Intake, kg	Feed Per Unit Gain, kg
Basal 0.11% P	78	0.00	0.61	-
	86	1.36	0.52	24.27
	72	2.27	0.60	16.65
	79	5.23	0.73	8.83
Monoammonium Phosphate 0.15%	74	2.73	0.54	12.44
	82	4.32	0.83	12.17
	76	5.91	0.85	9.14
	75	2.73	0.69	16.05
Monoammonium Phosphate 0.19% P	87	7.05	0.84	7.54
	90	4.32	0.74	10.86
	73	7.50	0.92	7.74
	88	5.68	0.70	7.75
Monosodium Phosphate 0.15% P	6	0.68	0.51	47.16
	89	0.00	0.59	-
	85	3.86	0.77	12.62
	77	5.00	0.75	9.47
Monosodium Phosphate 0.19% P	83	4.32	0.73	10.69
	93	5.91	0.76	8.06

TABLE 37. INDIVIDUAL DATA ON PHOSPHORUS LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL[a]

Phosphorus, Source and Percent	Lamb No.	Weeks on trial[b]			
		0	3	6	9
Basal 0.11%	78	4.75	4.23	5.50	6.71
	86	3.05	3.86	5.52	4.21
	72	3.90	4.57	4.85	3.25
	79	2.70	3.71	4.12	4.01
Monoammonium Phosphate 0.15% P	74	1.45	3.35	4.00	3.94
	82	4.05	4.59	6.22	4.31
	76	3.40	6.02	7.54	5.71
	75	3.90	5.66	5.95	5.59
Monoammonium Phosphate 0.19% P	87	2.85	5.11	7.26	4.96
	90	3.95	4.46	6.00	5.69
	73	4.15	4.01	6.30	5.11
	88	3.30	6.05	5.92	5.00
Monosodium Phosphate 0.15% P	6	2.75	5.26	7.55	5.68
	89	3.10	5.59	5.26	6.05
	85	3.45	6.15	5.33	5.68
	77	4.20	5.03	5.63	4.47
Monosodium Phosphate 0.19% P	83	3.35	4.35	6.82	4.40
	93	4.75	7.23	6.90	5.20

[a] Phosphorus concentration expressed as mg/100 ml of plasma.

[b] Each value under weeks 3, 6, and 9 is the average of three weekly sampling periods.

TABLE 38. INDIVIDUAL DATA ON CALCIUM LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL[a]

Phosphorus, Source and Percent	Lamb No.	Weeks on trial[b]			
		0	3	6	9
Basal 0.11%	78	8.90	10.29	11.13	9.21
	86	9.63	10.93	11.16	9.97
	72	9.55	10.94	10.88	10.27
	79	10.05	11.82	11.90	10.24
Monoammonium Phosphate 0.15% P	74	11.27	13.01	10.75	9.79
	82	10.30	9.95	10.91	9.72
	76	9.72	10.39	10.98	9.44
	75	9.90	10.07	10.15	9.28
Monoammonium Phosphate 0.19% P	87	10.67	9.95	10.42	9.74
	90	10.88	9.23	10.40	9.30
	73	9.63	10.13	10.11	9.24
	88	10.35	11.17	9.75	9.30
Monosodium Phosphate 0.15% P	6	11.12	10.60	10.64	9.92
	89	10.37	9.42	9.69	9.19
	85	10.82	11.79	10.82	9.56
	77	11.85	10.41	7.86	9.32
Monosodium Phosphate 0.19% P	83	11.57	11.73	10.71	9.63
	93	10.45	11.35	10.60	9.55

[a] Calcium concentration expressed as mg/100 ml of plasma.

[b] Each value under weeks 3, 6, and 9 is the average of three weekly sampling periods.

TABLE 39. INDIVIDUAL DATA ON MAGNESIUM LEVEL IN PLASMA OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL[a]

Phosphorus, Source and Percent	Lamb No.	Weeks on trial[b]			
		0	3	6	9
Basal 0.11%	78	1.84	1.97	2.15	2.04
	86	2.08	2.20	2.41	2.23
	72	2.04	2.33	2.60	2.56
	79	1.86	2.05	2.48	2.26
Monoammonium Phosphate 0.15% P	74	1.69	2.18	2.33	2.14
	82	1.56	2.00	2.12	2.05
	76	1.85	2.18	2.41	2.20
	75	1.61	1.95	2.03	2.07
Monoammonium Phosphate 0.19% P	87	1.73	2.13	2.36	2.23
	90	2.17	1.75	2.33	2.07
	73	1.57	2.16	2.33	2.10
	88	1.69	2.17	2.04	2.11
Monosodium Phosphate 0.15% P	6	1.66	2.01	2.17	1.99
	89	1.37	1.82	1.82	1.97
	85	2.15	2.60	2.44	2.15
	77	1.99	1.89	2.15	1.98
Monosodium Phosphate 0.19% P	83	2.43	2.60	2.71	2.40
	93	1.72	2.35	2.26	2.09

[a] Magnesium concentration expressed as mg/100 ml of plasma.

[b] Each value under weeks 3, 6, and 9 is the average of three weekly sampling periods.

TABLE 40. INDIVIDUAL DATA ON MEASUREMENTS AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

Phosphorus, Source and Percent	Lamb No.	Weight of Dry, Fat-Free Bone, gm	Ash, % of Dry, Fat-Free Bone	Phosphorus % of Ash	Calcium % of Ash
Basal 0.11% P	78	43.68	66.12	16.25	35.53
	86	49.19	65.57	15.28	35.42
	72	40.57	59.64	16.20	36.94
	79	49.67	65.61	15.73	33.80
Monoammonium Phosphate 0.15% P	74	38.43	58.89	16.43	36.48
	82	44.43	64.36	16.34	35.30
	76	47.31	66.56	16.42	36.18
	75	47.37	65.35	16.38	35.02
Monoammonium Phosphate 0.19% P	87	51.76	63.40	16.10	35.71
	90	39.26	65.92	16.98	36.01
	73	51.45	65.53	16.46	36.37
	88	46.77	66.87	16.70	35.04
Monosodium Phosphate 0.15% P	6	41.20	63.58	16.69	35.94
	89	40.04	66.61	15.77	33.38
	85	45.74	67.00	16.79	35.21
	77	51.48	66.34	16.70	34.63
Monosodium Phosphate 0.19% P	83	44.01	65.71	16.10	35.98
	93	47.85	66.85	16.49	35.08

TABLE 41. INDIVIDUAL DATA ON MEASUREMENT AND MINERAL CONCENTRATIONS OF THE RIGHT FEMUR OF LAMBS FED DIFFERENT SOURCES AND LEVELS OF PHOSPHORUS DURING A 9-WEEK GROWTH TRIAL

Phosphorus, Source and Percent	Lamb No.	Magnesium % of Ash	Volume of Dry, Fat-Free Bone, cc[a]	Dry, Fat-Free Weight of Bone, mg/cc[b]	Ash Weight of Bone mg/cc[c]
Basal 0.11% P	78	0.73	56.75	770	509
	86	0.70	59.75	790	453
	72	0.72	55.50	731	436
	79	0.68	68.25	728	477
Monoammonium Phosphate 0.15% P	74	0.67	50.50	761	448
	82	0.70	61.25	725	467
	76	0.75	53.50	884	588
	75	0.81	68.00	697	455
Monoammonium Phosphate 0.19% P	87	0.70	69.00	750	476
	90	0.73	49.25	797	525
	73	0.68	63.25	813	533
	88	0.78	64.00	731	489
Monosodium Phosphate 0.15% P	6	0.79	59.00	698	444
	89	0.69	53.00	755	503
	85	0.79	59.50	769	515
	77	0.73	64.50	798	529
Monosodium Phosphate 0.19% P	83	0.91	57.50	765	503
	93	0.81	55.50	862	576

[a] The volume of water displaced by the total dry, fat-free bone.

[b] Ratio of the total dry, fat-free weight in mg to the volume of water displaced by the total dry, fat-free bone.

[c] Ratio of the total ash weight in mg to the volume of water displaced by the total dry, fat-free bone.

TABLE 42. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	019	-8.04	37.73	34.39
20.00	031	-7.69	17.19	53.34
18.94	107	-6.81	16.55	41.01
32.50	020	35.38	23.02	16.40
32.50	029	27.78	-2.93	-2.27
32.50	079	28.77	19.30	42.98
32.50	090	28.61	10.20	48.40
47.50	20	45.33	4.50	-3.94
45.47	038	40.82	12.02	54.45
47.50	065	41.40	-23.13	-9.11
47.50	105	47.59	-1.47	8.18

---

[a] Magnesium intake per kg$^{0.75}$ body weight per day.

TABLE 43. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
19.01	90	2.27	-0.83	13.26
20.00	092	-2.79	22.06	16.80
20.00	165	11.30	-3.00	22.38
32.50	084	31.39	-3.01	18.45
32.50	100	27.25	-1.70	-2.16
32.50	127	40.35	2.01	27.86
32.50	200	32.57	-15.46	-5.37
47.50	64	42.75	-9.40	31.84
47.50	122	42.37	15.69	-6.95
47.50	195	50.94	2.17	15.54
47.50	196	46.49	0.85	-15.66

[a] Magnesium intake per kg$^{0.75}$ body weight per day.

TABLE 44. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PERCENT APPARENT ABSORPTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	085	4.50	18.44	4.11
20.00	106	7.25	-8.87	61.99
17.43	174	-0.97	-21.04	1.33
20.00	194	8.25	-6.12	40.94
32.50	97	24.35	-10.57	32.68
32.50	99	39.73	3.94	36.22
32.50	138	36.12	-3.40	47.05
32.50	197	33.68	1.08	7.52
44.11	18	48.84	-8.34	42.42
47.50	082	33.23	-4.42	20.74
47.50	88	51.39	9.16	20.74
47.50	198	40.70	2.62	28.19

[a] Magnesium intake per kg$^{0.75}$ body weight per day.

TABLE 45. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	019	-12.84	30.70	28.11
20.00	031	-15.49	14.57	6.48
18.94	107	-20.32	8.06	16.38
32.50	020	10.50	20.17	7.43
32.50	029	6.42	-8.88	-9.39
32.50	079	1.17	-11.04	42.47
32.50	090	5.68	5.02	6.39
47.50	20	5.76	-10.09	-6.74
45.47	038	12.75	2.76	28.06
47.50	065	1.56	-32.29	-14.61
47.50	105	13.60	-10.09	-8.29

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 46. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
19.01	90	-2.20	-6.90	10.00
20.00	092	-11.94	19.13	2.68
20.00	165	-1.19	-9.09	-0.63
32.50	084	2.47	-21.69	-8.86
32.50	100	4.29	-23.20	-17.33
32.50	127	8.15	-4.33	6.19
32.50	200	1.35	-36.58	-14.87
47.50	64	0.12	-25.33	-21.78
47.50	122	2.78	-10.80	-7.57
47.50	195	0.54	-12.96	-9.94
47.50	196	3.25	-11.03	-16.80

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 47. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PERCENT NET RETENTION OF MAGNESIUM, CALCIUM AND PHOSPHORUS

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	085	-0.64	5.63	3.39
20.00	106	-2.99	-16.04	-4.01
17.43	174	-4.18	-25.10	-13.68
20.00	194	4.34	-7.63	-5.96
32.50	97	1.88	-24.55	-11.85
32.50	99	13.37	-5.95	-1.13
32.50	138	6.76	-16.76	-6.70
32.50	197	0.89	-15.44	-25.46
44.11	18	6.95	-20.71	-7.63
47.50	082	5.04	-15.46	-6.32
47.50	88	7.66	-6.68	-2.48
47.50	198	10.24	-12.18	-14.36

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 48. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	019	4.79	7.02	6.38
20.00	031	7.79	2.69	46.85
18.94	107	13.51	8.48	24.63
32.50	020	24.86	2.85	8.97
32.50	029	21.34	5.95	7.12
32.50	079	27.58	30.34	0.51
32.50	090	22.92	5.17	42.00
47.50	20	39.55	14.51	2.80
45.47	038	28.06	9.22	26.39
47.50	065	39.83	9.16	5.49
47.50	105	33.98	8.61	16.58

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 49. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
19.01	90	4.47	6.07	3.26
20.00	092	9.14	2.93	14.12
20.00	165	12.49	6.09	23.02
32.50	084	28.91	18.68	27.31
32.50	100	22.95	21.50	15.27
32.50	127	32.19	6.34	21.56
32.50	200	31.20	21.11	9.50
47.50	64	42.61	15.92	53.73
47.50	122	39.57	26.57	0.72
47.50	195	51.48	15.13	25.49
47.50	196	43.23	11.88	1.14

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 50. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON URINARY EXCRETION OF MAGNESIUM, CALCIUM AND PHOSPHORUS, % OF INTAKE

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	085	5.14	12.80	0.72
20.00	106	10.24	7.17	66.01
17.43	174	3.21	4.05	15.01
20.00	194	3.89	1.58	46.91
32.50	97	22.45	13.97	44.53
32.50	99	26.35	9.89	37.35
32.50	138	29.34	13.44	53.76
32.50	197	32.77	16.52	32.98
44.11	18	41.87	12.37	50.05
47.50	082	28.17	11.03	27.07
47.50	88	43.71	15.92	23.23
47.50	198	30.45	14.80	42.55

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 51. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY LAMBS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML)

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	019	1.35	8.61	6.33
20.00	031	1.60	8.18	9.05
18.94	107	1.46	9.06	6.17
32.50	020	1.86	8.19	7.35
32.50	029	2.10	8.70	6.82
32.50	079	1.96	9.40	4.87
32.50	090	1.83	7.71	8.57
47.50	20	2.20	9.21	5.73
45.47	038	2.18	9.47	7.67
47.50	065	2.20	9.14	6.83
47.50	105	2.05	9.09	6.42

TABLE 52. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY YEARLINGS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML)

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
19.01	90	1.57	8.94	5.66
20.00	092	1.47	8.87	6.78
20.00	165	1.53	8.82	4.73
32.50	084	1.92	9.01	5.43
32.50	100	2.18	9.06	5.38
32.50	127	1.72	7.61	7.88
32.50	200	2.01	9.28	4.95
47.50	64	2.30	8.73	5.34
47.50	122	2.09	8.97	4.78
47.50	195	2.06	9.07	5.63
47.50	196	2.18	8.87	6.08

[a] Magnesium intake per $kg^{0.75}$ body weight per day.

TABLE 53. INDIVIDUAL DATA ON EFFECT OF MAGNESIUM INTAKE BY ADULTS ON PLASMA LEVELS OF MAGNESIUM, CALCIUM AND PHOSPHORUS (MG/100 ML)

Magnesium Intake, mg[a]	Sheep No.	Magnesium	Calcium	Phosphorus
20.00	085	1.40	8.79	4.13
20.00	106	1.74	7.95	4.81
17.43	174	1.15	8.66	4.32
20.00	194	1.16	8.04	4.66
32.50	97	2.02	8.73	4.88
32.50	99	1.90	8.08	4.93
32.50	138	2.11	8.29	7.54
32.50	197	1.79	8.46	4.39
44.11	18	2.28	8.66	5.87
47.50	082	2.32	8.83	6.87
47.50	88	2.20	8.66	5.57
47.50	198	2.09	8.54	5.93

[a] Magnesium intake per kg$^{0.75}$ body weight per day.

TABLE 54. INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces
019	191.78	207.21	90	174.54	170.56	085	181.50	173.37
031	202.51	218.07	092	172.13	177.12	106	180.17	167.13
107	170.45	182.11	165	173.86	158.28	174	181.39	183.20
						194	162.51	148.95
020	281.30	181.73	084	277.09	189.94	97	289.28	218.62
029	285.06	205.81	100	290.63	211.55	99	276.24	166.52
079	293.58	208.97	127	268.92	160.53	138	259.24	165.65
090	289.74	206.77	200	288.26	194.54	197	279.46	185.17
20	395.49	216.08	64	459.70	263.15	18	385.09	197.08
038	397.73	235.42	122	387.98	223.62	082	408.89	273.11
065	425.71	249.34	195	421.36	206.46	88	412.98	200.71
105	380.61	199.35	196	413.01	220.97	198	362.81	220.54

TABLE 55. INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces
019	20.00	21.62	90	19.01	18.58	085	20.00	19.11
031	20.00	21.55	092	20.00	20.57	106	20.00	18.56
107	18.94	20.23	165	20.00	17.75	174	17.43	17.60
						194	20.00	18.36
020	32.50	20.92	084	32.50	22.21	97	32.50	24.49
029	32.50	23.38	100	32.50	23.55	99	32.50	19.51
079	32.50	23.06	127	32.50	19.31	138	32.50	20.68
090	32.50	23.11	200	32.50	21.83	197	32.50	21.47
20	47.50	25.89	64	47.50	27.11	18	44.11	22.57
038	45.47	26.91	122	47.50	27.29	082	47.50	31.62
065	47.50	27.75	195	47.50	23.23	88	47.50	23.02
105	47.50	24.82	196	47.50	25.34	198	47.50	28.08

TABLE 56. INDIVIDUAL DATA ON RELATION OF FECAL MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces	Sheep No.	mg Mg Intake	mg Mg Feces
019	8.75	9.45	90	7.43	7.26	085	7.35	7.02
031	8.85	9.53	092	7.90	8.13	106	7.37	6.84
107	8.08	8.63	165	7.34	6.68	174	6.36	6.42
						194	7.50	6.88
020	13.82	8.93	084	13.04	8.94	97	12.72	9.62
029	14.11	10.19	100	12.64	9.20	99	11.93	7.19
079	13.43	9.56	127	12.64	7.55	138	11.89	7.60
090	13.96	9.96	200	12.78	8.63	197	12.23	8.11
20	20.71	11.32	64	18.40	10.54	18	17.24	8.82
038	20.11	11.91	122	18.50	10.66	082	18.71	12.50
065	20.22	11.84	195	17.98	8.81	88	17.46	8.48
105	20.02	10.49	196	17.46	9.34	198	17.37	10.56

TABLE 57. INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine
019	191.78	9.25	90	174.54	7.79	085	181.50	9.35
031	202.51	15.79	092	172.13	15.79	106	180.17	18.46
107	170.45	23.06	165	173.86	22.31	174	181.39	5.84
						194	162.51	6.36
020	281.30	69.90	084	277.09	79.99	97	289.28	64.94
029	285.06	60.80	100	290.63	66.78	99	276.24	72.82
079	293.58	80.95	127	268.92	85.57	138	259.24	76.12
090	289.74	69.99	200	288.26	90.04	197	279.46	91.47
20	395.49	156.31	64	459.70	195.93	18	385.09	161.28
038	397.73	111.59	122	387.98	153.53	082	408.89	115.20
065	425.71	169.35	195	421.36	216.71	88	412.98	180.51
105	380.61	129.22	196	413.01	178.46	198	362.81	113.19

TABLE 58. INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine
019	20.00	0.97	90	19.01	0.85	085	20.00	1.03
031	20.00	1.56	092	20.00	1.83	106	20.00	2.05
107	18.34	2.56	165	20.00	2.50	174	17.43	0.56
						194	20.00	0.78
020	32.50	8.05	084	32.50	9.36	97	32.50	7.27
029	32.50	6.91	100	32.50	7.43	99	32.50	8.53
079	32.50	8.93	127	32.50	10.42	138	32.50	9.50
090	32.50	7.42	200	32.50	10.10	197	32.50	10.61
20	47.50	18.73	64	47.50	20.18	18	44.11	18.47
038	45.47	12.76	122	47.50	18.74	082	47.50	13.34
065	47.50	18.86	195	47.50	24.38	88	47.50	20.70
105	47.50	16.09	196	47.50	20.47	198	47.50	14.42

TABLE 59. INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine	Sheep No.	mg Mg Intake	mg Mg Urine
019	3.75	0.42	90	7.43	0.33	085	7.35	0.38
031	8.85	0.69	092	7.90	0.72	106	7.37	0.76
107	8.08	1.09	165	7.34	0.94	174	6.36	0.21
						194	7.50	0.29
020	13.82	3.43	084	13.03	3.76	97	12.73	2.86
029	14.11	3.01	100	12.64	2.90	99	11.92	3.15
079	13.43	3.70	127	12.64	4.07	138	11.89	3.49
090	13.96	3.20	200	12.78	3.99	197	12.23	4.00
20	20.71	8.19	64	18.40	7.84	18	17.24	7.22
038	20.11	5.64	122	18.50	7.32	082	18.71	5.27
065	20.22	8.05	195	17.98	9.25	88	17.46	7.63
105	20.03	16.80	196	17.46	7.54	198	17.37	5.42

TABLE 60. INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER 1,000 KILOCALORIES OF METABOLIZABLE ENERGY INTAKE PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output
019	191.78	216.48	90	174.54	178.35	085	181.50	182.71
031	202.51	233.84	092	172.13	192.90	106	180.17	185.59
107	170.45	205.15	165	173.86	180.53	174	181.39	189.02
						194	162.51	155.35
020	281.30	251.59	084	277.09	269.09	97	289.28	283.58
029	285.06	266.64	100	290.63	278.30	99	276.24	239.35
079	293.58	289.94	127	268.92	247.10	138	259.24	241.75
090	289.74	273.15	200	288.26	284.55	197	279.46	276.65
20	395.49	372.42	64	459.70	459.09	18	385.09	358.31
038	397.73	347.03	122	387.98	377.16	082	408.89	388.32
065	425.71	418.67	195	421.36	423.16	88	412.98	381.20
105	380.61	328.58	196	413.01	399.44	198	362.81	333.72

TABLE 61. INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM$^{0.75}$ BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output
019	20.00	22.58	90	19.01	19.43	085	20.00	20.14
031	20.00	23.11	092	20.00	22.41	106	20.00	20.61
107	18.94	22.79	165	20.00	20.26	174	17.43	18.16
						194	20.00	19.14
020	32.50	28.96	084	32.50	31.56	97	32.50	31.76
029	32.50	30.28	100	32.50	30.98	99	32.50	28.05
079	32.50	31.99	127	32.50	29.73	138	32.50	30.18
090	32.50	30.53	200	32.50	31.93	197	32.50	32.07
20	47.50	44.62	64	47.50	47.29	18	44.11	41.05
038	45.47	39.67	122	47.50	46.03	082	47.50	44.96
065	47.50	46.61	195	47.50	47.61	88	47.50	43.72
105	47.50	40.91	196	47.50	45.81	198	47.50	42.50

TABLE 62. INDIVIDUAL DATA ON RELATION OF MAGNESIUM OUTPUT (FECAL PLUS URINARY) TO MAGNESIUM INTAKE PER KILOGRAM BODY WEIGHT PER DAY

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output	Sheep No.	mg Mg Intake	mg Mg Output
019	8.75	9.87	90	7.43	7.59	085	7.35	7.40
031	8.85	10.22	092	7.90	8.85	106	7.37	7.59
107	8.08	9.73	165	7.34	7.62	174	6.36	6.63
						194	7.50	7.17
020	13.82	12.36	084	13.04	12.71	97	12.73	12.48
029	14.11	13.20	100	12.64	12.11	99	11.93	10.34
079	13.43	13.27	127	12.64	11.62	138	11.89	11.09
090	13.96	13.16	200	12.78	12.62	197	12.23	12.11
20	20.71	19.50	64	18.40	18.38	18	17.23	16.04
038	20.11	17.55	122	18.50	17.98	082	18.71	17.77
065	20.22	19.89	195	17.98	18.05	88	17.46	16.11
105	20.03	17.29	196	17.46	16.88	198	17.37	15.98

TABLE 63. INDIVIDUAL DATA ON RELATION OF URINARY MAGNESIUM TO PLASMA MAGNESIUM[a]

Lambs			Yearlings			Adults		
Sheep No.	mg Mg Plasma	mg Mg Urine	Sheep No.	mg Mg Plasma	mg Mg Urine	Sheep No.	mg Mg Plasma	mg Mg Urine
019	1.35	0.47	90	1.57	0.59	085	1.40	0.87
031	1.60	0.75	092	1.47	1.24	106	1.74	1.70
107	1.46	1.37	165	1.53	1.96	174	1.15	0.49
						194	1.16	0.62
020	1.86	4.29	084	1.92	5.96	97	2.02	5.00
029	2.10	3.51	100	2.18	5.20	99	1.90	7.08
079	1.96	5.25	127	1.72	7.29	138	2.11	8.00
090	1.83	3.87	200	2.00	6.82	197	1.79	8.17
20	2.20	9.21	64	2.30	14.38	18	2.28	12.93
038	2.18	6.11	122	2.09	13.12	082	2.32	9.00
065	2.20	10.06	195	2.06	18.49	88	2.20	17.17
105	2.05	8.78	196	2.18	16.97	198	2.09	11.29

[a] Plasma magnesium concentration per 100 ml; urinary magnesium excretion per hour.

BIBLIOGRAPHY

Agricultural Research Council. 1965. The nutrient requirements of farm livestock; No. 2 ruminants. Agricultural Research Council, London.

Ammerman, C. B., R. M. Forbes, U. S. Garrigus, A. L. Neumann, H. W. Norton and E. E. Hatfield. 1957. Ruminant utilization of inorganic phosphates. J. Anim. Sci. 16:796.

Ammerman, C. B., R. Hendrickson, G. M. Hall, J. F. Easley and P. E. Loggins. 1965. The nutritive value of various fractions of citrus pulp and the effect of drying temperature on the nutritive value of citrus pulp. Proc. Fla. State Hort. Soc. 78:307.

Ammerman, C. B. and W. E. Thomas. 1955. Relative pH values and buffering capacities of the ruminal ingesta of lambs as affected by various forages. Cornell Vet. 45:443.

Annison, E. F. and D. Lewis. 1959. Metabolism in the rumen. John Wiley and Sons, New York.

Anonymous. 1964. Analytical methods for atomic absorption spectrophotometry. The Perkin-Elmer Corp., Norwalk, Connecticut.

Arias, C., W. Burroughs, P. Gerlaugh and R. M. Bethke. 1951. The influence of different amounts and sources of energy upon in vitro urea utilization by rumen microorganisms. J. Anim. Sci. 10:683.

Arrington, L. R., C. B. Ammerman, D. Yap, R. L. Shirley and G. K. Davis. 1962. Measurements of phosphorus availability for calves. J. Anim. Sci. 21:987.

Association of Official Agricultural Chemists. 1960. Official methods of analysis. 9th Ed., Washington, D. C.

Becker, R. B., G. K. Davis, W. G. Kirk, R. S. Glasscock, P. T. Dix Arnold and J. E. Pace. 1944. Defluorinated superphosphate for livestock. Fla. Agr. Exp. Sta. Bul. 401.

Beeson, W. M., R. F. Johnson, D. W. Bolin and C. W. Hickman. 1944. The phosphorus requirement for fattening lambs. J. Anim. Sci. 3:63.

Belasco, I. J. 1956. The role of carbohydrates in urea utilization, cellulose digestion and fatty acid formation. J. Anim. Sci. 15:496.

Blaxter, K. L. 1962. The energy metabolism of ruminants. Hutchinson, London.

Blaxter, K. L. and R. F. McGill. 1956. Magnesium metabolism in cattle. Vet. Rev. 2:35.

Blaxter, K. L. and J. A. F. Rook. 1954. Experimental magnesium deficiency in calves. 2. The metabolism of calcium, magnesium, and nitrogen, and magnesium requirements. J. Comp. Path. 64:176.

Blaxter, K. L., J. A. F. Rook and A. M. J. MacDonald. 1954. Experimental magnesium deficiency in calves. I. Clinical and pathological observations. J. Comp. Path. 64:157.

Bloomfield, R. A., G. B. Garner and M. E. Muhrer. 1960. Kinetics of urea metabolism in sheep. J. Anim. Sci. 19:1248. Abstr.

Bloomfield, R. A., E. O. Kearley, D. O. Creach and M. E. Muhrer. 1963. Ruminal pH and absorption of ammonia and VFA. J. Anim. Sci. 22:833. Abstr.

Bloomfield, R. A., E. G. Komer, R. P. Wilson and M. E. Muhrer. 1966. Alkaline buffering capacity of rumen fluid. J. Anim. Sci. 25:1276.

Bloomfield, R. A., M. E. Muhrer and W. H. Pfander. 1958. Relation of composition of energy source to urea utilization by rumen microorganisms. J. Anim. Sci. 17:1189. Abstr.

Bloomfield, R. A., R. P. Wilson and G. B. Thompson. 1964. Influence of energy levels on urea utilization. J. Anim. Sci. 23:868.

Bohman, V. R., O. L. Lesperance, G. D. Harding and D. L. Grunes. 1969. Induction of experimental tetany in cattle. J. Anim. Sci. 29:99.

Bunce, G. E., Y. Chiemchaisri and P. H. Phillips. 1962. The mineral requirements of the dog. IV. Effect of certain dietary and physiologic factors upon the magnesium deficiency syndrome. J. Nutr. 76:23.

Chicco, C. F. 1966. Some nutritional aspects of dietary magnesium in ruminants and poultry. Ph.D. dissertation, University of Florida, Gainesville.

Chicco, C. F., C. B. Ammerman, J. E. Moore, P. A. van Walleghem, L. R. Arrington and R. L. Shirley. 1965. Utilization of inorganic ortho-, meta- and pyrophosphates by lambs and by cellulolytic rumen microorganisms in vitro. J. Anim. Sci. 24:355.

Clark, Irwin. 1968. Effects of magnesium ions on calcium and phosphorus metabolism. Amer. J. Physiol. 214:348.

Clark, Irwin and Leonard Belanger. 1967. The effects of alterations in dietary magnesium on calcium, phosphate and skeletal metabolism. Calc. Tiss. Res. 1:204.

Clark, R. and W. A. Lombard. 1951. Studies on the alimentary tract of the Merino sheep in South Africa. XXII. The effect of the pH of the ruminal contents on ruminal motility. Onderstepoort J. of Vet. Res. 25:79.

Climatological Data National Summary. 1969-1971. U. S. Depart. of Comm. Environmental Data Service.

Coombe, J. B., D. E. Tribe and J. W. C. Morrison. 1960. Some experimental observations on the toxicity of urea to sheep. Australian J. Agr. Res. 11:247.

Duckworth, John and William Godden. 1941. The lability of skeletal magnesium reserves. The influence of rates of bone growth. Biochem. J. 35:816.

Duncan, C. W., C. F. Huffman and C. S. Robinson. 1935. Magnesium studies in calves. I. Tetany produced by a ration of milk or milk with various supplements. J. Biol. Chem. 108:35.

Dutton, J. E. and J. P. Fontenot. 1967. Effect of dietary organic phosphorus on magnesium metabolism in sheep. J. Anim. Sci. 26:1409.

Field, A. C. 1959. Balance trials with magnesium-28 in sheep. Nature 183:983.

Field, A. C. 1967. Studies on magnesium in ruminant nutrition. 7. Excretion of magnesium, calcium, potassium and faecal dry matter by grazing sheep. Brit. J. Nutr. 21:631.

Field, A. C., J. W. McCollum and E. H. Butler. 1958. Studies on magnesium in ruminant nutrition. Balance experiments on sheep with herbage from fields associated with lactation tetany and from control pastures. Brit. J. Nutr. 12:433.

Fiske, C. A. and I. Subbarow. 1925. The colorimetric determination of phosphorus. J. Biol. Chem. 66:375.

Forbes, G. B. 1959. Bone sodium and Na^{22} exchange: relation to water content. Proc. Soc. Exp. Biol. Med. 102:248.

Forbes, G. B. 1963. Mineral utilization in the rat. I. Effect of varying dietary ratios of calcium, magnesium and phosphorus. J. Nutr. 80:321.

Garces, M. A. and J. L. Evans. 1971. Calcium and magnesium absorption in growing cattle as influenced by age of animal and source of dietary nitrogen. J. Anim. Sci. 32:789.

Hale, W. H., F. Hubbert, Jr., E. L. Russell, W. C. Carey, Jr. and B. Taylor. 1962. Diammonium phosphate, urea and cottonseed meal as nitrogen sources for fattening beef cattle. Cattle Feeders Day, University of Arizona.

Hall, O. G., H. D. Baxter and C. S. Hobbs. 1961. Effect of phosphorus in different chemical forms on in vitro cellulose digestion by rumen microorganisms. J. Anim. Sci. 20:817.

Hansard, S. L., C. L. Comar and M. P. Plumlee. 1954. The effect of age upon calcium utilization and maintenance requirements in the bovine. J. Anim. Sci. 13:25.

Hansard, S. L. and H. M. Crowder. 1957. The physiological behavior of calcium in the rat. J. Nutr. 62:325.

Hart, E. B., G. Bohstedt, H. J. Deobald and M. I. Wegner. 1939. The utilization of simple nitrogenous compounds such as urea and ammonium bicarbonate by growing calves. J. Dairy Sci. 22:785.

Hillis, W. G. 1968. Nitrogen and phosphorus supplements for ruminant rations high in dried citrus pulp. M. S. Thesis, University of Florida, Gainesville.

Hjerpe, C. A. 1968. Influence of dietary magnesium on metabolism of calcium and magnesium in sheep. Amer. J. Vet. Res. 29:143.

Hogan, J. P. 1961. The absorption of ammonia through the rumen of the sheep. Australian J. Biol. Sci. 14: 448.

Huffman, C. F., C. L. Conley, C. C. Lighfoot and C. W. Duncan. 1941. Magnesium studies in calves. II. The effect of magnesium salts and various natural feed upon the magnesium content of the blood plasma. J. Nutr. 22:609.

Kaplan, A., A. L. Chaney, R. L. Lynch and S. Meites. 1965. Urea nitrogen and urinary ammonia. Std. Methods of Clin. Chem. 5:245.

Kercher, C. J. and L. Paules. 1967. Phosphorus sources for ruminants. J. Anim. Sci. 26:922. Abstr.

Knox, J. H. and P. E. Neale. 1937. Mineral supplements for cattle on phosphorus-deficient range. New Mexico State Agr. Exp. Sta. Bul. 249.

Lassiter, C. A., L. D. Brown and D. Keyser. 1962. An evaluation of diammonium phosphate as a nitrogen source for ruminants. Mich. Agr. Exp. Sta. Quart. Bul. 44(4):763.

L'Estrange, J. L. and R. F. E. Axford. 1963. The effect of low magnesium intake on lactating ewes. Proc. Nutr. Soc. 22:i.

L'Estrange, J. L. and R. F. E. Axford. 1964. A study of magnesium and calcium metabolism in lactating ewes fed a semi-purified diet low in magnesium. J. Agr. Sci. 62:353.

Lewis, D. 1957. Blood-urea concentration in relation to protein utilization in the ruminant. J. Agr. Sci. 48:438.

Lofgreen, G. P. 1960. The availability of the phosphorus in dicalcium phosphate, bonemeal, soft phosphate and calcium phytate for mature wethers. J. Nutr. 70:58.

Lomba, F., R. Paquay, V. Bienfet and A. Lousse. 1968. Statistical research on the fate of dietary mineral elements in dry and lactating cows. II. Magnesium. J. Agr. Sci. 71:181.

Long, T. A., A. D. Tillman, A. B. Nelson, W. D. Gallup and B. Davis. 1957. Availability of phosphorus in mineral supplements for beef cattle. J. Anim. Sci. 16:444.

MacDonald, D. E. and A. D. Care. 1959. Excretion of labelled magnesium by the sheep. Nature 184:736.

Martindale, L. and F. W. Heaton. 1964. Magnesium deficiency in the adult rat. Biochem. J. 92:119.

McAleese, D. M., M. C. Bell and R. M. Forbes. 1961. Magnesium-28 studies in lambs. J. Nutr. 74:505.

McDonald, F. W. 1948. The absorption of ammonia from the rumen of the sheep. Biochem. J. 42:584.

McLaren, G. A., G. C. Anderson, L. I. Tsai and K. M. Barth. 1965. Level of readily fermentable carbohydrates and adaptation of lambs to all-urea supplemented rations. J. Nutr. 87:331.

O'Dell, B. L., E. R. Morris and W. O. Regan. 1960. Magnesium requirement of guinea pigs and rats. Effect of calcium and phosphorus and symptoms of magnesium deficiency. J. Nutr. 70:103.

Oltjen, R. R., G. R. Waller, A. B. Nelson and A. D. Tillman. 1963. Ruminant studies with diammonium phosphate and urea. J. Anim. Sci. 22:36.

Ormsby, A. A. 1942. A direct colorimetric method for the determination of urea in blood and urine. J. Biol. Chem. 146:595.

Parr Manual No. 130. 1960. Oxygen bomb calorimetry and combustion methods. Parr Instrument Co., Moline, Ill.

Perez, C. B., R. G. Warner and J. K. Loosli. 1967. Evaluation of urea-phosphate as a source of nitrogen and phosphorus for ruminants. J. Anim. Sci. 26:810.

Preston, R. L. and W. H. Pfander. 1964. Phosphorus metabolism in lambs fed varying phosphorus intakes. J. Nutr. 83:369.

Reaves, J. L., L. J. Bush and J. D. Stout. 1966. Effect of different non-protein nitrogen sources on acceptibility of rations by dairy cattle. J. Dairy Sci. 49:1142.

Repp, W. W., W. H. Hale and W. Burroughs. 1955. The value of several non-protein-nitrogen compounds as protein substitutes in lamb fattening rations. J. Anim. Sci. 14:901.

Richardson, D., E. F. Smith, B. A. Koch and R. F. Cox. 1957. Sources of phosphorus for beef cattle. Kansas Agr. Exp. Sta. Circ. 349.

Richter, H. and Y. Lapoinie. 1962. New reagent for use in determination of blood urea nitrogen, with special reference to manual analysis. Clin. Chem. 8:335.

Robinson, R. A. and M. L. Watson. 1955. Crystal-collagen relationships in bone as observed in the electron microscope. III. Crystal and collagen morphology as function of age. Ann. N. Y. Acad. Sci. 60:596.

Rook, J. A. F. 1961. Rapid development of hypomagnesaemia in lactating cows given artificial rations low in magnesium. Nature 191:1019.

Rook, J. A. F. and C. C. Balch. 1958. Magnesium metabolism in the dairy cow. II. Metabolism during the spring grazing season. J. Agr. Sci. 51:199.

Rook, J. A. F. and J. E. Storry. 1962. Magnesium in the nutrition of farm animals. Nutr. Abstr. and Rev. 32:1055.

Russell, E. L., W. H. Hale and F. Hubbert, Jr. 1962. Evaluation of diammonium phosphate as a source of nitrogen for ruminants. J. Anim. Sci. 21:523.

Schaadt, H., Jr., R. R. Johnson and K. E. McClure. 1966. Adaptation to and palatability of urea, biuret and diammonium phosphate as NPN sources for ruminants. J. Anim. Sci. 25:73.

Simesen, M. G., T. Lunaas, T. A. Rogers and J. R. Luick. 1962. The endogenous excretion of magnesium in cattle. Acta. Vet. Scand. 3:175.

Smith, B. S. W. and A. C. Field. 1963. Effect of age on magnesium deficiency in rats. Brit. J. Nutr. 17:591.

Smith, R. H. 1959a. Calcium and magnesium metabolism in calves. 3. Endogenous fecal excretion and absorption of magnesium. Biochem. J. 71:306.

Smith, R. H. 1959b. Calcium and magnesium metabolism in calves. 4. Bone composition in magnesium deficiency and the control of plasma magnesium. Biochem. J. 71:609.

Smith, R. H. 1969. Absorption of major minerals in the small and large intestines of the ruminant. Proc. Nutr. Soc. 28:151.

Smith, R. H. and A. B. McAllan. 1966. Binding of magnesium and calcium in the contents of the small intestine of the calf. Brit. J. Nutr. 20:703.

Smith, R. H. and A. B. McAllan. 1967. Precipitation of magnesium in association with phosphate under the conditions obtaining in the calf ileum. Proc. Nutr. Soc. 26:xxxii.

Steel, R. G. D. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York.

Storry, J. E. and J. A. F. Rook. 1963. Magnesium metabolism in the dairy cow. V. Experimental observations with a purified diet low in magnesium. J. Agr. Sci. 61: 167.

Suttle, N. F. and A. C. Field. 1967. Studies on magnesium in ruminant nutrition. 8. Effect of increased intakes of potassium and water on the metabolism of magnesium, phosphorus, sodium, potassium and calcium in sheep. Brit. J. Nutr. 21:819.

Suttle, N. F. and A. C. Field. 1969. Studies on magnesium in ruminant nutrition. 9. Effect of potassium and magnesium intakes on development of hypomagnesaemia in sheep. Brit. J. Nutr. 23:81.

Thomas, J. W. 1959. Magnesium nutrition of the calf. Symposium of magnesium and agriculture. West Virginia University, p. 131.

Tillman, A. D. and J. R. Brethour. 1958a. Dicalcium phosphate and phosphoric acid as phosphorus sources for beef cattle. J. Anim. Sci. 17:100.

Tillman, A. D. and J. R. Brethour. 1958b. Ruminant utilization of sodium meta-, ortho- and pyrophosphates. J. Anim. Sci. 17:792.

Toothill, J. 1963. The effect of certain dietary factors on the apparent absorption of magnesium by the rat. Brit. J. Nutr. 17:125.

Visek, W. J. 1968. Some aspects of ammonia toxicity in animal cells. J. Dairy Sci. 51:286.

Walser, M. 1967. Magnesium metabolism. Rev. of Physiol., Biochem. and Exp. Pharm. Springer-Verlag, New York.

Wilson, A. A. 1960. Magnesium homeostasis and hypomagnesaemia in ruminants. Vet. Rev. 6:39.

Wise, M. B., A. L. Ordoveza and E. R. Barrick. 1963. Influence of variations in dietary calcium-phosphorus ratio on performance and blood constituents of calves. J. Nutr. 79:79.

Wise, M. B., R. A. Wentworth and S. E. Smith. 1961. Availability of the phosphorus in various sources for calves. J. Anim. Sci. 20:329.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

C B Ammerman

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

J A. Himes

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

C.B. Allen, Jr. CJS.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

R. H. Harms BLD

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

John E. Moore

This dissertation was submitted to the Dean of the College of Agriculture and to the Graduate Council, and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August, 1971

Dean, College of Agriculture

Dean, Graduate School

UNIVERSITY OF FLORIDA
3 1262 07332 069 8